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BOTANY

MORPHOLOGY AND PHYSIOLOGY

BOTANY

OUTLINES
OF
MORPHOLOGY AND PHYSIOLOGY

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EDITORS' PREFACE.

NOTWITHSTANDING the large number of scientific works which have been published within the last few years, it is very generally acknowledged by those who are practically engaged in Education, whether as Teachers or as Examiners, that there is still a want of Books adapted for school purposes upon several important branches of Science. The present Series will aim at supplying this deficiency. The works comprised in the Series will all be composed with special reference to their use in school-teaching; but, at the same time, particular attention will be given to make the information contained in them trustworthy and accurate, and to presenting it in such a way that it may serve as a basis for more advanced study.

In conformity with the special object of the Series, the attempt will be made in all cases to bring out the educational value which properly belongs to the study of any branch of Science, by not merely treating of its acquired results, but by explaining as fully as possible the nature of the methods of inquiry and reasoning by which these results have been obtained. Consequently, although the treatment of each subject will be strictly elementary, the fundamental facts will be stated and discussed with the fullness needed to place their scientific significance in a clear light, and to show the relation in which they stand to the general conclusions of Science.

In order to ensure the efficient carrying out of the general scheme indicated above, the Editors have endeavoured to obtain the co-operation, as Authors of the several treatises, of men who combine special knowledge of the subjects on which they write with practical experience in Teaching.

The volumes of the Series will be published, if possible, at a uniform price of 1*s.* 6*d.* It is intended that eventually each of the chief branches of Science shall be represented by one or more volumes.

G. C. F.,
P. M.

PREFACE.

Of late years several books, intended to serve as introductions to the rudiments of botanical knowledge, have been published, but there is still a lack of works of an intermediate class between these and the more complete treatises addressed to advanced students of the science. Hence, with the concurrence of the Editors of the Series in which it appears, it has been thought advisable to give to this volume a somewhat more advanced character than the Series generally is intended to have. It is hoped that, together with the volume on the 'Classification of Plants,' to be published very shortly, this work may serve as a basis for the botanical teaching in the higher classes of schools, and may also supply the wants of medical students and others who wish to acquire some knowledge of Botany, either as a preparation for the further study of that science, or as a branch of General Biology.

This volume is intended to place before the student the fundamental principles of the modern Morphology and Physiology of Plants. It will be necessary, however, in all cases for the teacher to supplement the instruction given by demonstrations from the objects themselves, as it is only by personal observation and practical work that the student can hope to obtain a sound knowledge of his subject.

In preparing this little book, ample use has been made of Sachs' 'Text Book of Botany,' of Prantl's 'Lehrbuch der Botanik,' and of Luerssen's 'Grundzuege der Botanik.' To all of these I hereby make the most grateful acknowledgments.

W. R. McNAB.

Royal College of Science, Dublin:
January 5, 1878.

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BOTANY.

GENERAL MORPHOLOGY AND PHYSIOLOGY OF PLANTS.

MORPHOLOGY OF PLANTS.

CHAPTER I.

THE CELL.

Nature of the Cell.—The simplest plant with which we are acquainted, the yeast-plant for example, consists of a single minute vesicle inclosing semifluid albuminoid contents: this structure is called a *cell.* Other plants, at the beginning of life, likewise consist of only a single cell, which divides and forms new cells, until at last, by repeated subdivision, the body of the plant is composed of a mass of cells united to form *cell-tissue.* All plants consisting of cell-tissue form separate cells at some period of their life; as for example pollen-grains and spores. Cells, whether separate or aggregated, have a regular life-history. They come into existence, increase in size, multiply, and reach maturity; then their activity diminishes, and at last they die. When first formed, cells are all exactly similar in appearance. This does not long continue, because every cell having some definite function to perform, soon becomes modified and adapted to its special duty in the economy of the plant. When thus adapted, mature cells differ very much from each other, and still more from their own youngest state, in size, position, and function.

When the cell has reached its stage of greatest activity, it consists of three concentrically arranged parts. At first only two (fig. 1, A), or perhaps even only one, of these parts may be distinctly seen, while in the later stages of its life, when activity has ceased, again only one, or at most two, of the parts remain. In the mature cell the three parts are :—(1) the firm, elastic, outer wall, the *cell-wall* (fig. 1, A B C, *h*) ; (2) the soft, inelastic, semifluid, albuminoid substance inside the wall called the *protoplasm* (fig. 1, A B C, *p*), in which is generally embedded a more solid rounded body, the *nucleus* (fig. 1, A B C, *k*) ; and (3) the watery fluid occupying the centre, the *cell-sap* (fig. 1, B C, *s*). In the young condition cell-sap is diffused through the protoplasm and cell-wall, a certain amount of water being absolutely necessary for the life of both. As the cell grows, the cell-sap also increases, forming drops or *vacuoles*[1] (fig. 1, B, *s*), which ultimately coalesce to produce the central cavity, without diminishing the quantity diffused through the protoplasm and wall. In some cases the cell in its youngest condition has no wall; hence in its simplest state a cell may be a mere wall-less mass of protoplasm, which, however, has the power of forming the wall and

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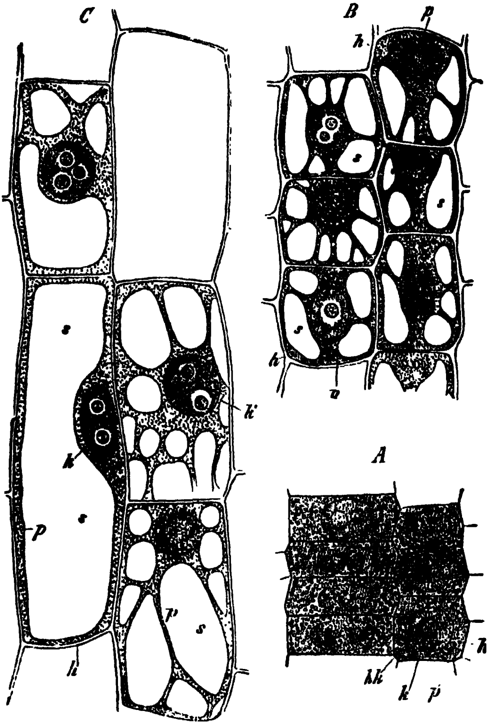
[1] It has been recently stated, apparently without sufficient evidence, that vacuoles arise by the division of pre-existing ones. They are now known to play an important part in the life of a cell.



Cells from the root of *Fritillaria imperialis* (× 550).

A, very young cell from near apex ; B, from 2 mm. above the apex ; C, from about 8 mm. above the apex. *h*, cell-wall ; *p*, protoplasm ; *k*, nucleus ; *k k*, nucleoli ; *s*, vacuoles and cell-sap cavity. (After Sachs.)

cell-sap. When the cell grows old and activity ceases, the protoplasm disappears entirely, the wall and cell-sap alone remaining; or a further change may take place, as in cork cells, where only the walls are left, the cavity being filled with air.

The *cell* is the ultimate organ or structural element of the plant; the most important part of the cell is the *protoplasm.* On its presence depends the activity of the cell; without it new cells cannot be formed, nor can new chemical compounds be elaborated. The substance of the cell-wall is formed by the protoplasm, which also furnishes the new material necessary for its growth. During the life of the cell many changes occur in the wall, such as increase in its size and thickness and modifications in its chemical composition, all depending on the activity of the protoplasm. In the protoplasm itself important changes take place. Thus it may divide and form new cells: or special granular contents, as starch, or coloured materials, as chlorophyll, may be developed. Lastly, the substances which either exist in solution in the cell-sap, or may crystallise out of it, are all products of the activity of the protoplasm.

The Cell-wall (fig. 1, A B C, *h*).—At first many cells are destitute of a wall, and consist of naked masses of protoplasm, to which the names of wall-less or primordial cells have been applied. By the activity of the protoplasm, the substance of the cell-wall is elaborated and gradually separated, appearing on its surface as a fine, bright skin, without visible openings, but easily permeable by water and gases. The thin walls of young cells consist chiefly of a peculiar substance called *cellulose* ($C_6 H_{10} O_5$) isomeric with starch. Cellulose occurs in a nearly pure state in the hairs of cotton. It is coloured blue by the action of sulphuric acid and iodine, or by Schulze's solution. Cellulose differs from starch in being slightly, if at all, affected by iodine, which turns starch blue at once. In addition to the cellulose, there exists in the cell-wall a small quantity of mineral matter or ash, a considerable quantity of water, and traces of protoplasm.

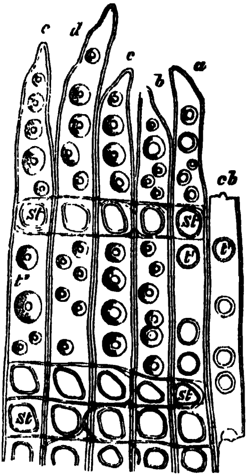
After the formation of the wall the dimensions of the cell rapidly increase, and generally the wall becomes thicker.

Continuity of Protoplasm.—It is very important to realise that the cellulose does not form a completely closed partition, cutting off the contents of one cell from those of the next one. It has been shown that innumerable fine strands of protoplasm, in many cases only ·00003 inch thick, pass through the cell-wall, connecting the contents. This continuity of protoplasm occurs in the living cells of all plants, and is of great importance in their life-history (*e.g.* germination of seeds).

Growth of the cell-wall.—When first formed, the cells are generally small in size; and if subsequent growth be inconsiderable, the cells may remain very minute during their whole life. In most cases, however, they grow very greatly in size, and at the same time change their form. Growth in size is rarely quite regular, so that the cell seldom retains its original form. In general, growth is irregular or *local*, being limited to certain parts of the wall. Thus, cells alter their shape during growth and assume the varied forms seen in the higher plants; the elongated pointed prosenchymatous bast-cells, and star-like parenchymatous cells, affording very good examples. Local growth of the cell-wall is seen in the formation of root-hairs from the epidermal cells of roots, or in the growth of the pollen-tube from the pollen-grain. Growth in thickness generally accompanies growth in size, and may be either regular or irregular. Regular thickening is rare, while irregular thickening is very common, and gives rise to the markings seen in the interior of cells. The growth of the cell-wall in thickness takes place by the *apposition* of new material, *i.e.* by the deposition of fresh layers on pre-existing ones; these layers consist of minute granules of cellulose—the microsomata—secreted as granules of a proteid nature in the endoplasm. From the endoplasm they pass into the ectoplasm, from which, as granules of cellulose, they are deposited on the pre-existing cell-wall. The cell-wall is uniformly or locally thickened according as the microsomates are uniformly or locally deposited. Subsequent stretching of a cell-wall thickened by apposition was considered sufficient to explain the increase in area of a cell-wall. Now there is a tendency to introduce another factor, the *intercalation* or *intussusception* of new particles of cellulose between pre-existing ones. The whole growth of a cell-wall, both in thickness and extent, was at one time supposed to be due to intercalation, not to apposition. From the preceding it is obvious that the thickening of the cell-wall is internal (centripetal). The markings on spores, pollen-grains, coats of some seeds, may be differently produced.[1]

The irregular thickening is the cause of the peculiar sculpturing so characteristic of the walls of tissue-cells. The centripetal thickening may assume the form of rings, or of a spiral thread, or of reticulations, and the thickenings are in consequence called annular, spiral, or reticulated. Often the thickening matter is very feebly attached to the wall, and the rings or spirals can be readily separated. In other cases the characteristic appearance is due not to the thickened but to the unthickened parts, which remain as pits of different forms. The chief forms of pitted markings are the ordinary pits, bordered pits, and scalariform markings. Simple pits are shallow cylindrical depressions, generally placed rather close together, the spaces between the pits consisting

FIG. 2.



Longitudinal section of wood of *Pinus sylvestris* (× 200).

Bordered pits, *t t' t''*, increasing in age; *a e*, wood-cells, *e* oldest, *a* youngest; *c b*, wood-cell of Cambium; *s t*, large pits, where medullary rays touch wood-cells. (After Sachs.)

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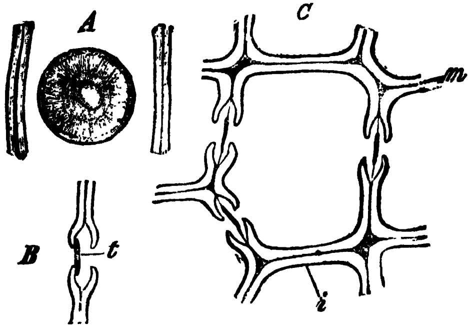
[1] It is beyond the limits of this book to consider the several explanations given.

of the thickened part of the wall. In some cases the pits are very deep and may branch; they are then distinguished as canals, the depth being due to the great thickness of the cell-wall. Bordered pits of large size are seen in the wood of pine-trees (fig. 2, *t t′*, *t″*), and small bordered pits exist in many flowering plants. In the bordered pit the depression is not cylindrical but funnel-shaped, being widest at the bottom where the wall is left unthickened, and narrowest above. Looked at from above, the mouth of the pit appears as a small round hole, while the expanded lower part forms a circular border, hence the name (fig. 3, B, C). In the bordered pits of cycads[1] the 'pit' is an elongated narrow opening instead of being circular as in most plants. When both 'border' and 'pit' are greatly

FIG. 3.



Pinus sylvestris. *A*, a bordered pit in surface view; *B* in section, *t*, torus; *C*, cross-section of an entire tracheide. (After Strasburger.)

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[1] A waning group of plants, allied to pine-trees.

elongated and narrow, then the marking called scalariform is produced. The scalariform markings occur typically in the ferns and lycopods. In cell-tissue with pitted markings, the markings on both sides of the common wall accurately correspond. This is shown in bordered pits; the pit-membrane is, in reality, the floor of two bordered pits. At first the cavity of the bordered pit is like a plano-convex lens, the plane side towards the wall; but after absorption of the wall it is shaped[1] like a double convex lens. Partial absorption of the wall of a cell is not uncommon. By the absorption of the transverse walls separating elongated cells joined in rows, a *cell-fusion*, or *vessel* is produced. When the transverse walls are pitted and absorption of the unthickened part takes place, then the *sieve-vessel* or bast-vessel is formed. Openings in cells as in those of the leaves of Sphagnum are produced by absorption of portions of the wall. It sometimes happens that the pressure of the contents in a living parenchymatous cell, next to a dead vessel (in the wood), is so great that an intervening pit-membrane bulges into the cavity of the vessel. This projection, followed by protoplasm, may divide to form a mass of large isodiametric cells, tending to fill up the cavity of the vessel. Such abnormal groups of cells are called *Tyloses*, and occur in the wood of the vine and other plants. As the cell-wall increases in thickness, a peculiar striation is often observed. This striation, well seen in the tracheïdes[2] of a pine, is due to the apposition of fresh layers of cellulose, and the subsequent alternation of more and less watery layers.

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[1] More correctly speaking, ceases to be a pit, as in old wood.

[2] The markings in fine tracheïdes are, apparently, of the same nature as the spiral thickening in a protoxylem vessel.

During the growth of the cell-wall changes in its chemical composition often occur, either partially or completely. These changes are of as much importance in the life-history of a plant as are the formation of bone, muscle, nerve, &c., in that of an animal. These are, first, the ligneous or woody change; secondly, the suberous or corky change; and thirdly, the mucilaginous change. In the first, the wall becomes woody as in the wood of the stem of forest trees, easily permeable by water, without swelling up to any considerable degree. Wood is coloured yellow by sulphuric acid and iodine or by Schulze's solution, is dissolved in concentrated sulphuric acid, and swells up in ammoniacal solution of cupric oxide. In the second, the wall becomes wholly or partially converted into cork, the wall is elastic, not easily permeable by water, and is coloured yellow by sulphuric acid and iodine or by Schulze's solution. The cork is dissolved[1] by nitric acid and potassium chlorate, or by boiling caustic potash. In cork-cells the wall is entirely changed, while in spores, pollen-grains, and epidermal cells the outer part only is changed, the inner part being unaltered cellulose. The third or mucilaginous change renders the walls soft and gelatinous; they become hard and horny when dried, but swell up enormously when placed in water. Sulphuric acid and iodine, and Schulze's solution generally colour the walls blue. This change is seen in the cells of Fucaceæ, and in Laminaria, and in the seed-coats of flax and quince.

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[1] Not by sulphuric acid.

Mineral matters are often deposited in large quantities, uniformly throughout the wall. These are generally either silica or calcium carbonate. If the walls containing silica be burned, the perfect silicious skeleton remains behind, or the vegetable matter may be removed by the action of strong mineral acids. Silica is largely developed in the cell-walls of diatoms, leaves of beech, and stems of equisetums. Calcium carbonate occurs amorphous in corallines, and in the vessels of Cucurbita. The cystoliths of the Indian rubber and Acanthaceæ are plugs of cellulose impregnated with carbonate of lime. Crystals of calcium oxalate occur in the walls of the cells of Welwitschia, Dracæna, and in many fungi.

Degradation-products of the cell-wall are often of importance. Such a product is the gum of the cherry-tree formed by the degradation of the walls of vessels or special cells in the wood parenchyma. Gum arabic, gum senegal, and gum tragacanth, all owe their origin to degradation of the cells in the stem, pith, or medullary rays. Gum resins as myrrh and bdellium, and the resin of Xanthorrhœa, have a similar origin.

Protoplasm (fig. 1, A B C, *p*).—The protoplasm consists of a mixture of albuminoids, water, and a small quantity of mineral material or ash. It is a very complex substance, and contains, at some time or another, all the chemical constituents of plants.

When dead it can be coloured by carmine, the colouring matter passing through the wall of the cell without colouring it, and deeply staining the protoplasm. It gives the chemical reactions of albumen or white of egg, coagulating at a temperature of about 50° Cent., or when alcohol or dilute mineral acids are applied. Iodine colours it brown, by the deposit of particles of iodine, and concentrated sulphuric acid renders it rose-red. Protoplasm is a soft mass, varying in consistency according to the quantity of water present in it, but it is never a true fluid. In general it is granular, and contains large particles of matter such as starch granules, or globules of oil. Rarely it is homogeneous and transparent. When granular, a delicate, homogeneous, external, firmer, bounding layer may be detected, the ectoplasm or primordial utricle (the rest being the endoplasm).

In the interior of the protoplasm numerous vacuoles form (fig. 1, B C, *s*). The water, which saturates the whole wall and protoplasm, increases in quantity during growth and collects to form these vacuoles. As the cell grows and more water accumulates, the vacuoles increase in size and number, until by their coalescence the protoplasm remains as a sac lining the interior of the cell-wall, and sending protoplasmic threads in various directions across the cavity (fig. 1, B C, *p*). Ultimately these threads disappear, and all the vacuoles coalesce to form a large central cell-sap cavity (fig. 1, C). If dilute nitric acid be now applied to the cell, the protoplasm contracts and separates from the wall. The description of the mode of origin of vacuoles here given may have to be modified in the light of recent researches. It is possible that vacuoles, in some cases at least, are due to the division of pre-existing ones.

In the cells of most of the higher plants, there exists a more solid rounded body, the *nucleus*[1] (fig. 1, A B C, *k*), but it is often wanting in the lower ones.[2] It is always embedded in the protoplasm, and is a part of it. In the nucleus one or two, or sometimes more, granules are often noticed, called the nucleoli (fig. 1, A B C, *k k*). Vacuoles also occur in it.

Living protoplasm usually exhibits peculiar movements. These may either take place when the protoplasm is inclosed in a cell-wall, or when it is wall-less. All the movements depend on the action of light, heat, and oxygen upon the living protoplasm. The movements occurring inside cell-walls are of two kinds. In the first the granules in the protoplasm are seen flowing from one part to another in a regular stream, generally to and fro from the nucleus. This is seen in many hairs, as in those of the stamen of Tradescantia, or the stinging hairs of the nettle, and is distinguished as the movement of *circulation*, the granules circulating as it were in the protoplasm. In other cells the whole protoplasmic sac moves, carrying with it nucleus and granular contents, all of which rotate in the cell, moving up one side and down the other. This second movement is distinguished as

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[1] See *note* 1, page 164.

[2] The number of plants of which this can be said is gradually decreasing, with advances in methods of research.

rotation,[1] and is seen in the cells of the Vallisneria and Anacharis. The movements of wall-less masses of protoplasm are also of two kinds. The first, or ciliary motion, is seen in zoogonidia or zoospores, the whole cell moving about rapidly by means of prolongations of the ectoplasm, the vibratile cilia. In the second, the mass of protoplasm not only changes its position, but changes its external form, and from the similarity of the movement to that seen in Amœba or the white blood corpuscle, the motion is called *amœboid.* It occurs in the amœboid stage of the Myxomycetes, a group of doubtful position. Two other movements have recently been described. The aggregation of the protoplasm of the cell into rounded masses, constantly changing their form and position, is seen in the cells of carnivorous plants (tentacles of Drosera) during the absorption of nitrogenous matter. The last movement is that described by Francis Darwin, namely, the protrusion of filaments of protoplasm, having amœboid movements, from the cells of the glandular hairs of Dipsacus sylvestris.

Formation of new Cells.—One of the most important functions of living protoplasm is the formation of new cells. The whole or a part only of the protoplasm of a pre-existing cell becomes rearranged and assumes a new form, the first or mother-cell forming one or more daughter-cells. There are several different modes of cell-formation, but we may best consider two groups of subordinate divisions.

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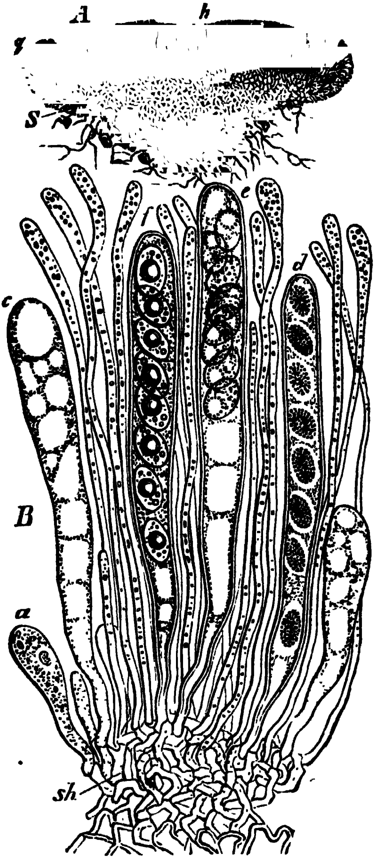
[1] The movements of rotation and circulation, forms of contractility of the living protoplasm, are very general in plant-cells. The plants mentioned are merely convenient examples.

FIG. 4.

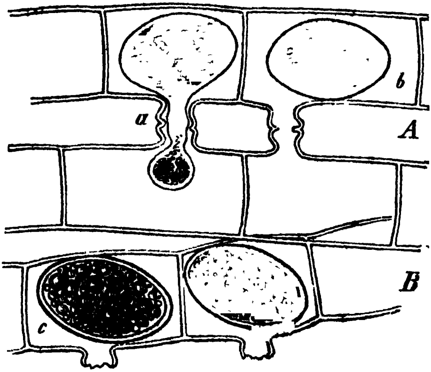


Peziza convexula.

A, section of plant (× 20); *h*, hymenium, with asci; B, portion of hymenium (× 550); *a-f*, asci, with spores forming by free-cell formation in different stages of development. (After Sachs.)

I. *Formation of vegetative cells.*—In growing vegetative organs new cells are formed by division (fig. 13), the whole mass of the protoplasm dividing into two new cells, which may be equal or unequal in size. The nucleus of the mother-cell does not disappear, but undergoes a complex series of changes (karyokinesis), finally dividing into two daughter-nuclei. The daughter-nuclei, with the protoplasm of the mother-cell in which they are embedded, become separated from one another by the formation of a cell-wall, and thus form two new cells.

FIG. 5.



Spirogyra longata.

A, cells in conjugation; *a*, fusion of protoplasm going on; *b*, fusion complete; B, young zygospores (× 550). After Sachs.)

II. *Formation of reproductive cells.*—There are several different ways in which the cells connected with the process of reproduction are formed, and they are all distinguished by the rounding and contracting of the protoplasm. The new wall forms on the whole surface of the daughter-cells, and this may take place when the cell-formation is going on, or after it has been completed. We may distinguish four varieties of formation of reproductive cells.

1. *Division.*—The entire protoplasm of the mother-cell divides into four or more rounded masses. In the pollen-grains of the higher plants and in the spores of mosses and vascular cryptogams, the nucleus of the mother-cell divides by repeated bipartition into four nuclei, around which the protoplasm aggregates to form the four new cells, and these are then liberated from the mother-cell. The wall develops around each of the daughter-cells, either during or after division. In other cases the protoplasm breaks up into many daughter-cells,[1] which escape as wall-less zoospores or zoogonidia in many Thallophyta. After swarming for some time, each zoospore may settle down, secrete a cell-wall, and give a new plant.

2. *Rejuvenescence.*—The whole mass of protoplasm of the mother-cell contracts and escapes from the wall as a new daughter-cell, which afterwards developes a wall. The germ-cell of many cryptogams, and the zoospores of Vaucheria, Œdogonium, and Stigeoclonium are formed in this way.

3. *Free-cell formation.*—The ascospores in the asci of the Ascomycetes (fig. 4, B *a*—*f*) and the germinal

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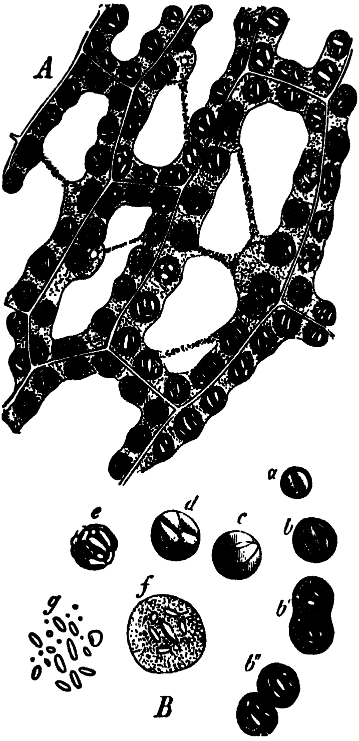
[1] After repeated division of the mother-cell nucleus. **In no case of cell-division does the nucleus of the dividing cell dissolve and disappear. Nuclei are never 'freely' formed, but result from the division of pre-existing ones.**

cells and endosperm cells in the embryo-sac of phanerogams are thus formed. The nucleus of the mother-cell undergoes repeated division, the whole of the protoplasm of the mother-cell is not used up in the process of division, and the cell-walls of the daughter-cells do not form, if at all, until the nuclear divisions are completed.

FIG. 6.



Chlorophyll granules in cells of leaf of *Funaria hygrometr* 550'.

A, granules of chlorophyll, with contained starch grains, imbedded in the protoplasm of the cells ; **B**, separated chlorophyll granules containing starch ; *a*, *b*, young granules ; *b' b''*, chlorophyll granules dividing ; *c*, *d*, *e*, old chlorophyll granules ; *f*, granule swollen up by action of water ; *g*, starch granules remaining after chlorophyll destroyed by action of water. (After Sachs.)

4. *Conjugation.*—In conjugation, as in fertilisation, two or more nucleated masses of protoplasm unite together, becoming contracted and rounded, a wall then forming round the new daughter-cell or zygospore

(fig. 5, A B). The mode of cell-formation by conjugation is characteristic of Spirogyra, species of Ectocarpus, Mucor, Desmids, &c.

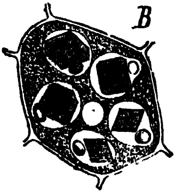
In plants, two or more modes of cell-formation may be observed either at the same or at different times. It will be noticed that by division and free-cell formation the number of cells is increased; in rejuvenescence the number remains the same, while in conjugation and fertilisation the number of cells is at first diminished.

Substances contained in Protoplasm.—The protoplasm forms granular and coloured contents, which are extremely important in the economy of the plant. Some always remain imbedded in the protoplasm, and disappear with it; while others may remain in the cell, but no longer increase in size or number after they have ceased to be in contact with protoplasm. The most important substances contained in the protoplasm are plastids including chlorophyll, crystalloids, aleurone grains, fat, and starch.

Plastids.—Plastids are minute proteid granules found in large numbers in cells, comparable to the nuclei in increasing in number by the division of pre-existing ones. They are classified according to their colour, which also serves to indicate their function, into leucoplastids (colourless), chloroplastids or chlorophyll grains (green), and chromoplastids (red, orange, &c.). All three kinds are changeable into one another by a change of circumstances. Leucoplastids are found more especially in cells not exposed to light (*e.g.* growing points of stems, tubers of potato, orchids, &c.), are usually spherical or rod-like, and in addition to becoming chloroplastids in the light, have as their chief function the formation of starch in the dark.

Chlorophyll.—Chloroplastids are the well-known chlorophyll-grains to which green cells owe their colour. The chlorophyll-grain consists of two parts: a colourless solid portion of proteid nature, giving the granule its consistence, form, and size; and a green colouring matter, the chlorophyll, the composition of which is still unknown. The colour can be readily removed in solution by the action of benzole, chloroform, or alcohol, the colourless protoplasm granule remaining behind, unaltered in size or shape. The solution is bright green by transmitted, and red by reflected light. The spectrum shows seven absorption-bands, the strongest being between the lines B and C of the solar spectrum. When the plant is deprived of light or etiolated, the granules form, but not the green colouring matter. The same occurs when the plant is deprived of iron as a constituent of its mineral food, the plant being then chlorotic. The form of the chloroplastid varies in the lowest plants—kidney-shaped (*Pleurococcus*), stars (*Zygnema*), plates (*Closterium*), or spiral bands (*Spirogyra*), giving a very characteristic appearance to the cells. In many of the lower plants, the chlorophyll is completely obscured by the presence of red (*phycoerythrin*), olive green, (*phycophaein* or *melanophyll*), or bluish (*phycocyan* or *phycochrome*) colouring matter, to which the red, brown, and bluish green algæ owe their colour. The function of chlorophyll in the nutrition of the plant is most important. The process of assimilation or the fixing of carbon by plants, depends on the action of chlorophyll on carbon dioxide in presence of water under the influence of sunlight. When exposed to light each chlorophyll-grain develops a number of starch grains in its substance. The starch formed during the day under the influence of sunlight is dissolved, most probably by the ferment diastase, during the night, and used either for purposes of growth, as in the division and enlargement of cells, or it is removed and stored up under the influence of leucoplastids, for future use, in some reservoir. Chromoplastids are proteid granules, more or less crystal-like, orange, yellow, red, &c., giving colour to many flowers (*e. g.* petals of Viola) and fruits,[1] and thus helping in the propagation of the species.

FIG. 7.



Cell of endosperm of *Ricinus communis*, Castor-oil seed (× 800) in dilute glycerine. Large transparent aleurone grains, with crystalloids and rounded globoids. (After Sachs.)

Crystalloids.—In the cells of many plants, as for example the tubers of the potato, and in fatty seeds, as the Brazil-nut, and castor-oil, crystal-like bodies (fig. 7) are to be met with, often in abundance. They assume the form of cubes, octohedra, tetrahedra, and rhombohedra, and are readily distinguished from true crystals by their not having very definite and clearly defined angles and edges, and by their swelling up and altering their angles when placed in dilute caustic potash. The crystalloids are seen when a transverse section of the endosperm of the castor-oil seed is placed in dilute glycerine. Crystalloids are exceedingly minute, reserve proteid granules deposited as the ripening seed becomes dehydrated, to be consumed at its germination.

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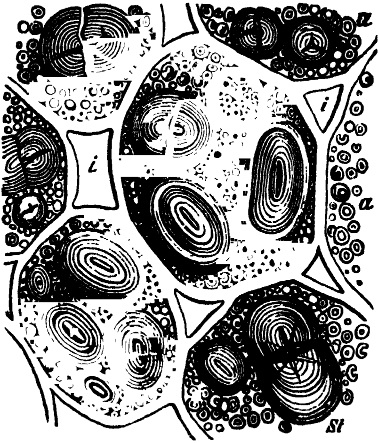
[1] It must not be overlooked that some flowers and fruits owe their bright colour to substances diffused in the cell-sap (*e. g.* petals of Pelargonium).

Aleurone Grains are rounded grains of small size

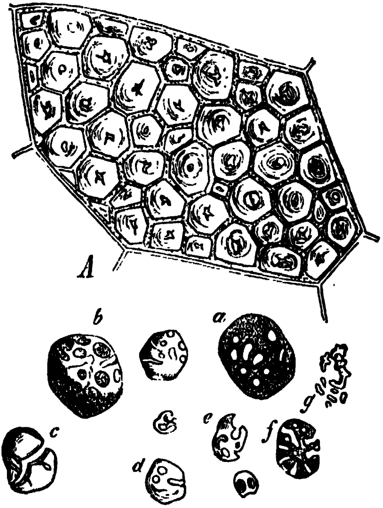
FIG. 8.



Cells of cotyledon of *Pisum sativum*, Pea (× 800). *St*, starch granules with central hilum and concentric striæ; *a*, granules of aleurone; *i*, intercellular spaces. (After Sachs.)

(fig. 8, *a*) imbedded in the protoplasm of many seeds, and appearing shortly before ripening. The grains consist of proteid substances, often contain crystalloids (fig. 7), and peculiar rounded bodies (fig. 7) called globoids, consisting of a combination of phosphoric acid with lime and magnesia. Cells containing aleurone grains are best observed in strong glycerine. Aleurone grains are soluble in caustic potash. The globoids are insoluble in caustic potash but soluble in dilute acids, as acetic acid. In the cells of the cotyledon of the pea, starch grains occur along with many aleurone grains, in the very thick protoplasm filling the cell. In the fatty seeds of the castor oil, globoids occur with crystalloids in the aleurone grains.

FIG. 9.



Cell of endosperm of *Zea mais*, Maize (× 800). Thin plates of protoplasm separating the polygonal starch grains.

-*g*, granules from germinating seed of maize becoming dissolved and disintegrated. (After Sachs.)

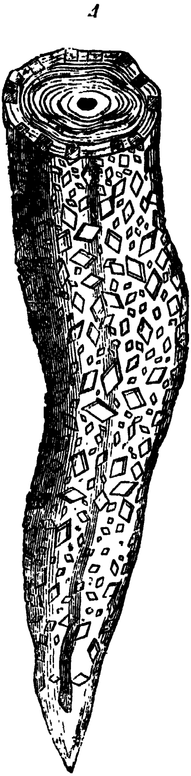
Fat occurs in protoplasm, and may take the place of starch in the cells of seeds as the reserve carbohydrate.

Starch occurs abundantly in the cells of most plants at some period of their growth. It is generally in the form of granules, varying in shape, being commonly oval, rounded, or lenticular (fig. 9, A). When acted on by boiling water, caustic potash, or other reagents, the grains swell up and form a paste. In appearance the granule is a transparent body marked at one part with a dark spot called the hilum, and having concentric lines called the striae encircling the hilum (fig. 8, *st*). The starch granule only grows as long as it is embedded in the protoplasm. At first it is a minute solid homogeneous body, formed in nearly every plant, under the influence of leucoplastids (in the dark) or chloroplastids (in the light). The centric hilum of a small grain becomes excentric owing to the mode of deposition of new layers of starch between the plastid and the previously formed part of the starch grain. A leucoplastid usually forms only one grain beside, and in close contact with itself. A chloroplastid forms a number, and imbedded in its substance. The stratification of a starch grain is due to the alternation of dense and less dense layers (a perfectly dry grain does not lose its stratification), and to the growth of the grain by apposition.

The starch granules consist of starch-substance, water, and a very small quantity of mineral matter, or ash. The starch-substance belongs to the group of the carbohydrates like cellulose, and has the same chemical composition. It can be separated into two substances called granulose and starch-cellulose, the latter forming only from two to six per cent. of the grain. The granulose is readily soluble in dilute mineral acids and saliva, the starch-cellulose remaining behind as a skeleton (fig. 9, *f*, *g*). By applying iodine solution, the granulose is at once coloured blue, while the skeleton of starch-cellulose becomes brown.

Some grains have only one hilum, others have two or more; the former are simple, the latter compound grains, both kinds occurring in the potato. When the chlorophyll-grains develop starch granules, the granules are generally minute, numerous, and often aggregated together. The starch formed in the chlorophyll-grains becomes re-dissolved after its formation, and the substance is conveyed either to those parts of the plant where new cells are being formed, or to some reservoir of nutrient materials, where it is stored up for future use. Although the starch granule only grows when in contact with the protoplasm, it may be stored in cells from which the protoplasm has almost disappeared; but it is generally in cells rich in protoplasm, as in the cotyledons or

FIG. 10.



endosperm of seeds. When germination takes place, the starch granules change their appearance, and the starch undergoes chemical changes. The change in appearance is due to the absorption of the granulose, the starch-cellulose skeleton remaining behind, to be, however, ultimately dissolved (fig. 9, *a*—*g*).

Starch is very widely distributed in plants, and the granules often assume a characteristic form and size. The starch granules of the potato and pea are oval in form, the former having one lateral hilum, occasionally two or more, while the latter have a central hilum. The granules of wheat starch are lenticular with a central hilum, while those of rice are exceedingly minute. Peculiar starch grains occur in the laticiferous cells of Euphorbia (fig. 30). The difference in the size and appearance of the starch granule is often of importance in medico-legal questions.

Cell-sap (fig. 1, B, C).—The cell-sap, as already mentioned, saturates the whole of the cell-wall, and protoplasm, and all the bodies contained in it, and also fills the vacuoles and the centre of the protoplasm sac. Many substances elaborated by the protoplasm remain in solution in it, as also mineral matters taken up in solution from the soil; others separate in definite forms. The substances that remain in solution are certain mineral salts, cane and grape sugar, tannin and the glucosides, inuline, the vegetable acids, such as citric and malic, and numerous colouring matters, such as the red and blue colours of many flowers (anthocyan) and of fruits. Certain mineral salts often crystallise out naturally, and other substances can be rendered visible by proper treatment, as when inuline crystallises out after the prolonged action of alcohol.

Crystals in cells and cell-walls.—The substances which crystallise out of the cell-sap may either form their crystals in the cavity or in the wall of the cell. These crystals sometimes consist of calcium phosphate, but generally of calcium oxalate, those of the latter salt being of two different forms. When the calcium oxalate crystallises with six equivalents of water, prisms and octohedra belonging to the dimetric system are formed: when only with two equivalents of water, then in raphides or needle-like crystals, belonging to the monoclinic system. Raphides often occur in large bundles in elongated cells filled with cell-sap but with no protoplasm. Most frequently the prismatic or octohedral crystals occur in groups in the interior of the cell, but in the cells of many Coniferæ and Gnetaceæ, as Welwitschia mirabilis (fig. 10), crystals of calcium oxalate occur in the outer layers of the thickened wall of the cell, in which case they are of small size and very numerous.

The presence of calcium carbonate has been already referred to (p. 11).

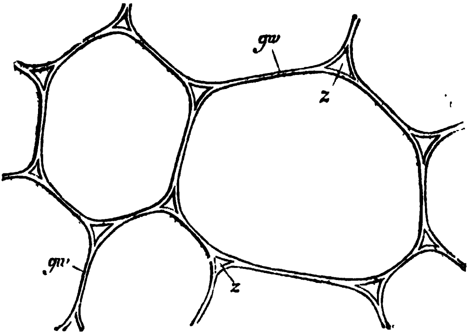
CHAPTER II.

THE TISSUES.

Aggregation of Cells to form Tissues.—Every aggregation of cells governed by a common law of growth may be termed a tissue. Tissues generally consist of cells formed by the repeated division of one or more mother-cells, the daughter-cells being in connection from the beginning. These are true tissues. In some cases the cells are separate and coalesce to form a false tissue. A false tissue may also be formed by the interlacing of rows of hyphal threads, as in lichens and fungi.

Cells may occur singly, but they are generally

FIG. 11.

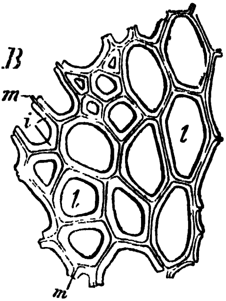


Transverse section of stem of *Zea mais* (× 550). Succulent parenchyma.

gw, simple plate of cellulose, forming the partition wall between two cells: *z*, *z*, intercellular spaces caused by splitting during rapid growth. (After Sachs.)

united together in various ways. The following are the chief varieties:—(1) *Cell-masses* are formed when the cells are united in all directions of space, the whole not necessarily having any definite external form. As examples we may cite the tissues of most plants, *e. g.* the ground tissue of ferns and monocotyledons, the pith of dicotyledons, the pulp and hard endocarps of fleshy fruits. (2) *Cell-rows* have the cells in contact by their ends, thus producing a filament. Many thallophytes consist of cell-rows, as Spirogyra, Œdogonium, and the hyphæ of funguses; many hairs, the vessels or cell-fusions in the fibro-vascular bundles, and the laticiferous vessels are examples occurring in the higher plants. (3) *Cell-surfaces* have the cells forming a single layer united in two directions of space. Examples of cell-surfaces are afforded by Ulva and other thallophytes, and by the leaves of some liverworts. In the higher plants cell-surfaces also occur, as the epidermis and the layer of cells separating the air-spaces in the stems of Nuphar and Musa. (4) *Cell-bundles*, a band or bundle of similar cells, as seen in Rhizomorpha, and in many of the Phæophyceæ, or in the bundles of sclerenchyma in ferns, or the bast fibres in the phloem of dicotyledons. (5) *Cell-groups.*—Families of similar cells, as in many of the thallophytes, as Chroococcus, or groups of cells occurring in the tissues of higher plants, as the sclerenchyma in the pulp of the pear, or in cork. (6) *Separate cells*, either originally separate or becoming so during growth; or single remarkable cells occurring in the tissues of the higher plants. Many of the lower plants consist of separate cells or idioblasts, and the curious star-like cells in the stems of Nuphar also

FIG. 12.



Cells of wood of young stem of *Helianthus*, Sun-flower (× 800). *l*, cavity of cell; *m*, middle lamella; *i*, thickened portions of wall. (After Sachs.)

belong to the same group. When cells are originally joined, and then isolate themselves, they may be distinguished as eremoblasts.

Walls of Tissue-cells.—The wall between two cells appears at first as a simple plate of cellulose (fig. 11). As it grows older and becomes thickened, chemical and physical changes may occur, so that ultimately there appears to be a middle lamella and a thickened part of the wall on each side (fig. 12). The middle lamella[1] is not a special structure or a variety of intercellular substance, but only a specially formed part of the common wall. The middle lamella generally loses its original cellulose composition, and can be dissolved by the action of potassium chlorate and nitric acid, the modified parts separating from one another. The markings on cell-walls generally occur symmetrically on each side of the middle lamella, the pores on one side corresponding to the pores on the other, except in the case of spiral, annular, and reticulated markings.

The walls of tissue-cells may, under certain circumstances, become wholly or partially absorbed. Partial absorption is to be seen with ease in sieve-vessels. Complete absorption occurs frequently in the transverse walls separating cell-rows in the higher plants, and a cell-fusion, or true vessel, is formed. Milk-vessels afford good examples; these also frequently branch and anastomose.

Intercellular Spaces.—After the rapid growth of the thin cell-walls, the middle lamella often exhibits minute, approximately triangular, spaces, where the walls of cells meet (fig. 11).—These are minute intercellular spaces, and are met with abundantly in certain tissues. When the splitting of the middle lamella is carried to the furthest possible extent, the cells separate, as in many ripe fruits. In other cases the middle lamella splits between two or more cells, and a large intercellular space is produced. The large intercellular spaces are called lacunæ, and like the minute ones above-mentioned, contain air. Lacunæ are seen in many water-plants, as in Nuphar. Intercellular spaces[1] must not be confounded with large air-cavities met with in the hollow stems of equisetums, grasses, and Umbelliferæ, formed by the rupturing and drying up of masses of tissues. Resin and gum-canals of Umbelliferæ, Araliaceæ (fig. 33), and Coniferæ are true intercellular spaces. The intercellular air-spaces are

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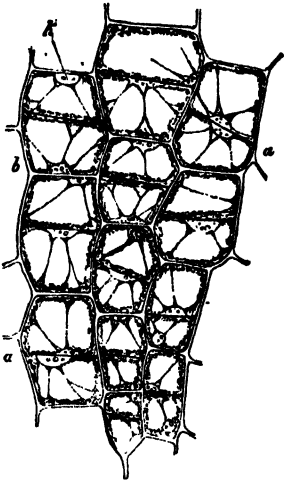
[1] The middle lamella is the pit-membrane of a bordered pit.

FIG. 13.



Cells of stem of *Vicia faba* (× 300). Secondary Meristem cells in process of division.

k, nucleus; dividing, *a*; fully divided, *b*. (After Prantl.)

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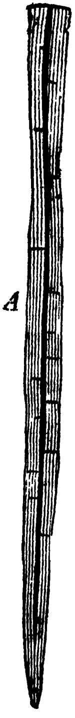
[1] Intercellular spaces due to the splitting of the cell-wall are schizogenetic, due to the disintegration of cells, lysigenetic.

in connection with the stomata of the epidermis, thus putting the tissues in the body of the plant into communication with the outer air.

FIG. 14.



End of a bast cell, prosenchymatous, in section (× 300).

Apex pointed; wall much thickened and pitted. (After Prantl.)

Forms and Systems of Tissues.—Meristem tissue consists of cells capable of dividing, certain of the daughter-cells retaining the power, others being converted into *permanent* tissue (fig. 13). Permanent tissue is the name given to that form in which the cells are no longer capable of division. Meristem cells are small and nearly similar in appearance; they have thin smooth walls, and are filled with protoplasm. Two varieties of meristem may be distinguished, called primary and secondary. Primary meristem forms the whole tissue of very young organs, or parts of organs, as the apex of the root and stem, and the youngest leaves, also the whole of the young embryo. It is from this primary meristem [1] that all the tissues are differentiated. Secondary meristem consists of thin layers of permanent tissues which have assumed the power of dividing to form now permanent tissue. Three kinds of secondary meristem may be distinguished. (1) Cambium[1] between the phloem and xylem of the fibro-vascular bundles (fig. 22, *c*); (2) Interfascicular cambium between the cambium forming bundles (fig. 22, *c b*), and (3) phellogen or cork cambium (fig. 18). Permanent tissue is formed by the further development of cells derived from the primary and secondary meristem, and which have lost the power of dividing, and assume some permanent form. Many different kinds might be mentioned, but it will be sufficient to distinguish two well-marked varieties, differing in the form and connection of the cells. The first is distinguished as *parenchyma* (fig. 11). The cells are more or less cubical, the length not exceeding the breadth;

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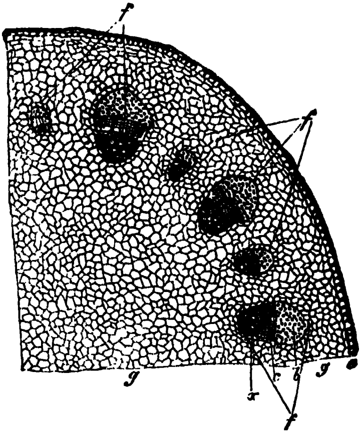
[1] The persistence in a higher plant at the tips of stem, root and their branches, of functional embryonic tissue, has nothing comparable in an animal.

FIG. 15.



Transverse section of petiole of *Helleborus* (× 20), showing the three systems of tissues.

e, epidermal; *f*, fibro-vascular; *x*, xylem; *c*, *b*, phloem—*c*, soft bast; *b*, bast fibres; *g*, ground or fundamental tissue. (After Prantl.)

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[1] Fascicular cambium is, if not primary meristem, a direct derivative of it.

the transverse walls broad, possessing intercellular spaces, where the walls meet, and generally having thin walls. The second is *prosenchyma* (fig. 14). The cells are always much longer than they are broad; the ends are tapering and overlapping, the walls are thick, and no intercellular spaces are to be met with. When the walls of both prosenchyma and parenchyma become very thick, hard, and frequently dark-coloured, then from this hard nature of the wall the tissue is distinguished as *sclerenchyma.* In the higher plants, both meristem and permanent tissue are to be met with at the same time, and also different forms of the two groups. The different tissues arrange themselves in these higher plants into three groups or systems. (1) The Epidermal or Limitary system, which bounds or limits the body of the plant externally (fig. 15 *e*); (2) The Fibro-vascular system, traversing the plant-body like strings, and consisting largely[1] of fibre-like prosenchymatous cells, and vessels (fig. 15 *f*); and (3) The Ground or Fundamental System which fills up all the rest of the space inside the epidermal tissues (fig. 15, *g*). These three systems of tissues are to be met with in the full-grown parts of the higher plants (fig. 15, *efg*), but in the young parts, those still in the condition of protomeristem, this differentiation is not yet seen. As the tissues are traced backwards from the growing point every transition from protomeristem to complete separation of the three systems may be noticed.

The Epidermal or Limitary Tissues (fig. 15, *e*).—

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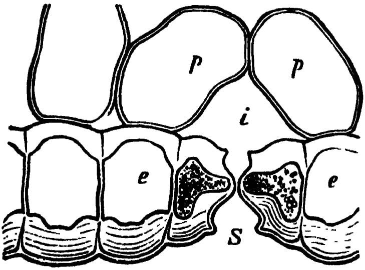
[1] There are vascular bundles from which prosenchymatous elements are quite absent.

In the lowest plants the outer layer cannot be readily distinguished from the ground tissue, and it consists of slightly modified superficial cells of that ground tissue. In the higher plants there is a well-marked external layer called the epidermis. It covers almost all the younger parts of the plant, and consists usually of a single layer of cells having no intercellular spaces except, in aërial parts, the stomata. The epidermis can generally be separated as a fine transparent skin. It is usually a cell-surface, one cell thick, but in a few exceptional cases, as in the India-rubber leaf, the originally simple epidermis divides into two or more layers, the outer layer retaining the ordinary epidermal character. A special modification of the epidermis is seen in the aërial roots of some orchids, often distinguished under the name of velamen and formed by the repeated division of the epidermal cells. In many water-plants, some roots, the epidermis hardly differs from the subjacent cells. On the parts of plants exposed to the air, as stems and leaves, the epidermis forms *stomata*, and often *hairs*. The epidermal cells rarely contain chlorophyll, but frequently have colouring matter in solution in the cell-sap. The epidermis cells vary in shape, but generally the form has some relation to the part on which they are developed. Leaves which grow greatly in length have the epidermal cells elongated; when the leaves are not elongated the cells may be more or less rounded, or have sinuous margins. The outer wall of the epidermal cells generally becomes partially suberous; the corky portion forms a continuous layer, the cuticle, which covers the whole epidermis. Particles of wax are embedded in the cuticle of many parts of plants, and appear on the surface in the form of fine grains, producing a bluish coating, as the bloom on a plum or grape, or they may collect in quantity, as on the cuticle of the fruits of the candleberry myrtle (*Myrica*), or the stem of the wax-palm.

Stomata are openings in the epidermis serving mainly to regulate transpiration or the escape of water vapour into the air. They are in connection with intercellular spaces (fig. 16), air-cavities, and the air-bearing canals. Each stoma consists of two guard cells formed by the division of one of the epidermal cells. The guard cells are usually semilunar in form, and have an opening or intercellular space between them, formed by the splitting of the middle lamella. Stomata open or close according to the intensity of the light, by the curving or straightening of the guard cells. Sometimes the guard cells are surrounded by two or more cells different in appearance from the other cells of the epidermis. Stomata are found on all parts of plants above ground, rarely on parts under water, and never on roots. They are very

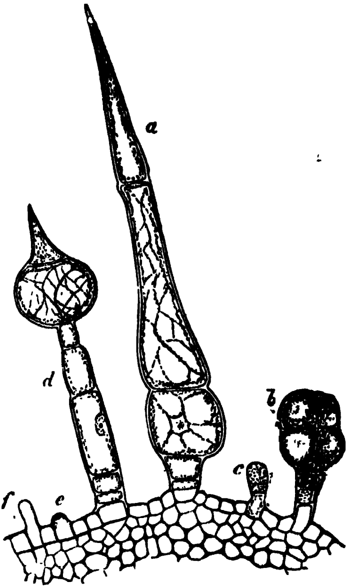
FIG. 16.



Transverse section of epidermis and stoma of leaf of *Hyacinthus orientalis* (× 800).
e, epidermal cells, with thickened outer wall and cuticle; *p*, parenchyma of leaf; *i*, air-space; *s*, opening of the stoma between the two guard cells right and left. (After Sachs.)

numerous on the leaves, generally on the under-surface, but sometimes equally on both sides, as in many monocotyledons. The number of stomata varies much in different plants, there being occasionally from 300 to 700 in a square millimetre.

FIG. 17.



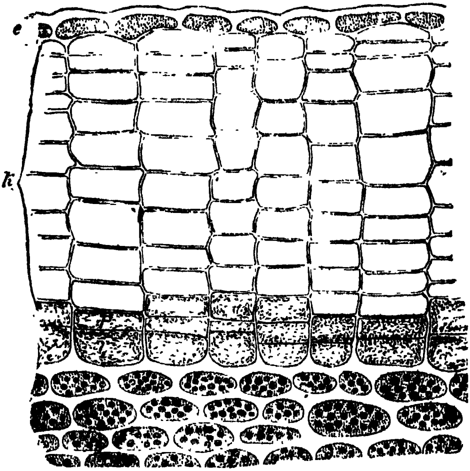
Transverse section of epidermis and subjacent tissue of ovary of *Cucurbita* (× 100). *a*, hair, of a row of cells; *b*, *d*, glandular hairs in different stages of development; *c*, *f*, *e*, youngest stages of development of glandular hairs. (After Prantl.)

Hairs (fig. 17) are formed by the epidermis, being usually outgrowths of single epidermal cells (fig. 17, *ef*). A hair may consist of a single cell (root-hairs) or by division may become a cell-row (stamen of Tradescantia), a cell-surface (dry scaly hairs of ferns), or a cell-mass (the spiny-hairs or prickles of the rose). Such cell-masses arise, not from an epidermal cell alone, but from a cell of the subjacent tissue in addition, and are, on this account, sometimes distinguished as 'emergences.' When the hair forms a terminal cell-mass, by the division and enlargement of the cells at the apex, a glandular hair is formed. Star-like hairs are not uncommon; the papilla formed by the epidermal cell divides transversely, the upper part again divides and forms the rays of the star. The contents of the cells of many hairs disappear, the cell-walls become much thickened and coloured, and mineral matter, as silica or calcium carbonate, is deposited. Stinging hairs, as in the nettle, are placed upon a protuberance formed by the tissue below the epidermis, and are distinguished by the secretion of an acrid fluid. Special glandular hairs, called colleteres by Hanstein, secreting a mixture of mucilage and resin (blastocolla), are developed on the buds of dicotyledons (Æsculus), or on leaves, stipules, or the sheath of the leaf. The varieties of hairs are very numerous, and different names have been given to special forms.

Secondary Limitary Tissue.—Parts of plants which are of long duration or which increase greatly in diameter, as the stems of dicotyledonous trees and of conifers, soon lose their epidermis, and a new or secondary limitary tissue, generally arising from the ground tissue, takes its place. The new tissue is very rarely formed from the epidermis itself, but generally from the tissues immediately below. It consists of flattened or brick-shaped cork-cells, arranged regularly in rows, and placed parallel to the surface of the part on which they are developed (fig. 18). The cells are filled with air, have no intercellular spaces except at special points; the walls give the reaction of cork and are nearly impermeable by water.

Cork cells are usually formed by the repeated tangential division of a zone of cells, known as the cork-cambium or phellogen. The phellogen cells are secondary meristem cells, and generally arise (Populus, Ulmus, Pinus) from the cortical cells im-

FIG. 18.



Transverse section of one-year-old stem of *Ailanthus glandulosus* (× 350).

e, epidermis withered; *k*, cork-cells, formed by the inner cells with protoplasm, the cork cambium or phellogen, *p*; *r*, the phelloderma. (After Prantl)

mediately below the epidermis. One, or rarely more, layers of cells may be given off from the phellogen on its inner side, being known as the phelloderm cells (fig. 18, *r*). Cork cells, phellogen, and phelloderm, together constitute periderm.[1] The epidermis and its appendages, thrown off as a result of the secondary thickening of the stem, are thus replaced by a continuous layer of periderm. Care should be taken not to confuse cork cambium with true or vascular cambium. The cork cambium forms new annual rings, as the ordinary cambium forms rings of wood, a condition seen in a transverse section of cork. On the massive trunks of dicotyledonous trees, layers of cork form at different depths, not only in the ground-tissues, but occasionally in the fibro-vascular tissues themselves. All tissues external to the layers of cork, die and dry up, forming a strong, hard, massive, protecting tissue, the bark or rhytidome completely surrounding the inner living tissues. The nature of the bark varies in different trees, and frequently gives a characteristic appearance to the trunk. The bark may scale off or be marked with deep longitudinal furrows, depending on the circumferential growth of the stem, and on the arrangement of the cork cells and bast of the fibro-vascular bundles. In an ordinary tree, the youngest twigs are covered by the epidermis, the young branches by periderm, and the trunk by the true bark; all the three stages depending on the age of the part.

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[1] The limits of the periderm are indicated by the coincidence of the radial walls of the cells, as seen in cross section.

Lenticels.—Here and there in the stems of most plants possessing periderm, the cork cells[1] become rounded, separate more or less from one another, forming a spongy mass or *lenticel.* Lenticels have much the same relation to periderm that stomata have to epidermis.

The Fibro-vascular Tissues (fig. 15, *f*).—In the higher plants bundles of cells and vessels are to be met with in the ground tissue of the stems, leaves, and roots. These are generally known as the vascular bundles, or less correctly, as the fibro-vascular bundles. A vascular bundle is a strand of conducting tissue, usually extending continuously from the root, through the stem, and into the leaves, anastomosing at the nodes. Different groups of plants have characteristic courses of their vascular bundles.

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[1] Walls not necessarily suberised.

In its earliest stage, the fibro-vascular bundle becomes separated from the protomeristem as a string of similar cells, which are generally elongated, and have no intercellular spaces. This meristem tissue, which has not yet begun to differentiate into the various permanent forms, is called *procambium.* As the bundle grows older, the procambium gradually becomes converted into permanent tissues—the vessels of the wood and of the bast. In some cases the whole of the procambium becomes changed into permanent tissue, but in others, as for example in the bundles of the stems of dicotyledons, a layer of cells capable of dividing remains between the outer and inner portions of permanent tissue. This meristem zone is called the *cambium,*[1] and upon its presence the further development of the bundles depends. The bundles containing cambium being capable of further growth, are called open or indefinite; while those with no cambium, as in monocotyledons, are incapable of further growth, and are called closed or definite.

Xylem and Phloem.—The permanent tissues of the fibro-vascular bundle can be divided into two groups (fig. 15, *x* and *c b*). In one group the wood (fig. 15,

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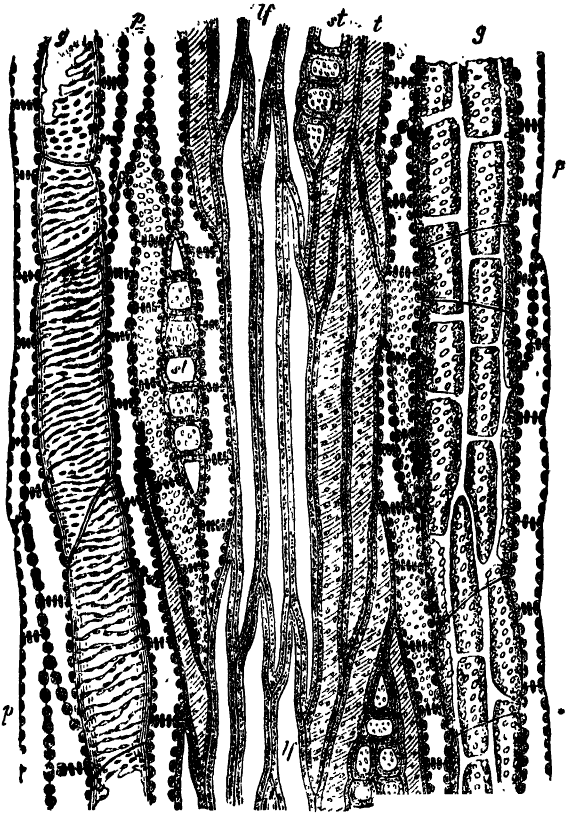
[1] It should be remembered that the cambium is only a single layer of cells thick.

x), the walls of the essential elements, the wood vessels, become ligneous. In the other group, the bast (*c b*), the walls of the essential elements, the bast vessels or sieve-tubes, remain cellulose. The former is called the xylem or hadrome, the latter the phloem or leptome. In closed or definite bundles, no cells capable of division remain between the phloem and xylem, but in open or indefinite bundles, a layer of meristem cells, the cambium, exists. By the activity of the cambium, new or secondary xylem is periodically formed on the one side, and new phloem on the other. The newly-formed xylem and phloem often differ from that developed directly from the procambium, hence it is necessary to describe the kinds of cells met with in closed bundles and in open bundles, before the latter are modified by the activity of the cambium.

Both the xylem and the phloem parts of the bundle consist typically of three kinds of cells. The xylem (fig. 19) consists of (1) Cell-fusions or vessels,[1] the woody tubes, which are variously designated, according to the special form of the markings on their thickened cell-walls, as spiral, annular, reticulated, scalariform; (2) Elongated, narrow, prosenchymatous cells with overlapping ends, the woody fibres or wood prosenchyma; and (3) A variable quantity of parenchymatous cells, the wood parenchyma. The xylem of the fibro-vascular bundle thus consists essentially of three sets of cells, viz., the wood vessels, the wood prosenchyma, and the wood parenchyma. In the same way the phloem also consists of three sets of

[1] Vessels are in many cases, really tracheïdes.

FIG. 19.

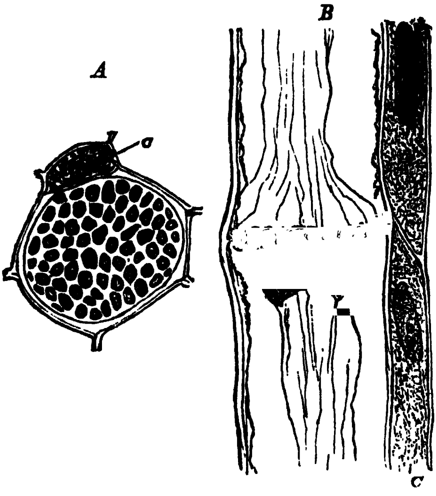


Longitudinal tangential section of stem of *Ailanthus*, showing secondary xylem of fibro-vascular bundles.

g, *g*, wood-vessels; *p*, wood-parenchyma; *t*, *lf*, wood-prosenchyma of two varieties; *t*, tracheides, with pitted and spiral markings, and *lf*, libriform or bast-like wood fibres; *st*, medullary rays cut across. (After Sachs.)

cells. (1) The bast-vessels or sieve tubes (sieve vessels, fig. 20) with thin walls, containing a slimy proteid mixture, but having the transverse walls thickened and perforated with fine open pores; (2) The bast fibres, or bast prosenchyma, long, much thickened, flexible, prosenchymatous cells; and (3) Bast parenchyma, thin-walled parenchymatous cells. Small nucleated cells, known as companion-cells, probably of important function, accompany sieve-tubes. Sieve-tubes consist of living cells, wood-vessels of dead

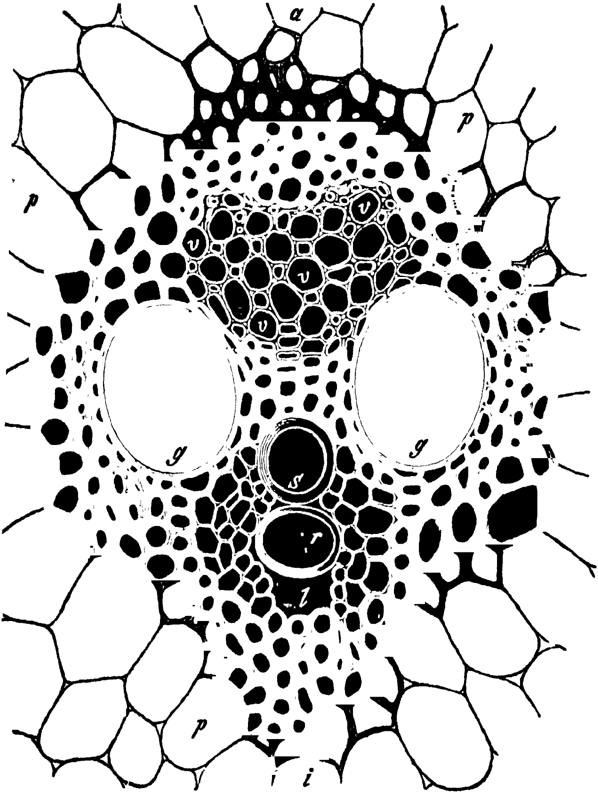
FIG. 20.



Cucurbita Pepo, sieve-tubes. × 540.

A, sieve-tube in cross-section showing sieve-plate; *c*, companion cell with nucleus; *B*, sieve-tube in longitudinal section. (After Strasburger.)

FIG. 21.

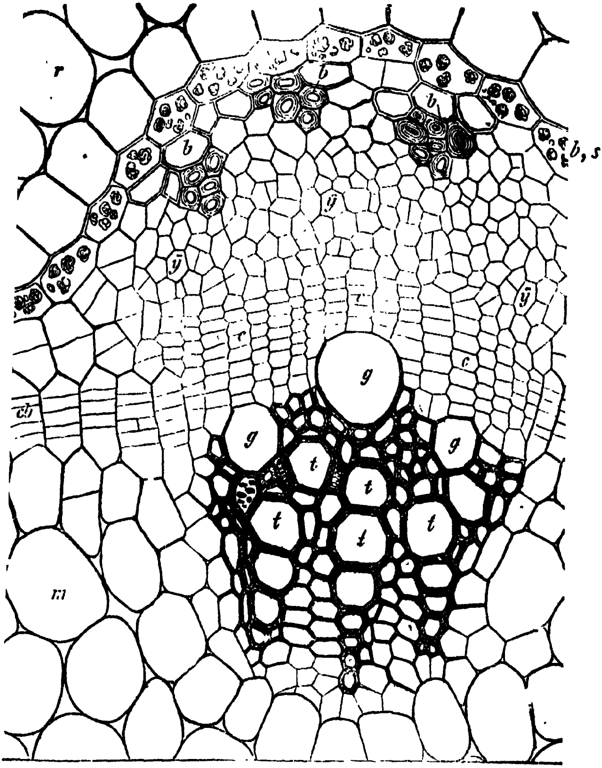


Transverse section of fibro-vascular bundle of *Zea mais* (× 550).

p, thin-walled parenchyma of ground-tissue of, *a*, outer and, *i*, inner part of stem, with thick-walled prosenchymatous ground-tissue internal to it; *g*, *g*, large pitted vessels; *s*, spiral vessel; *r*, isolated ring of annular vessel; *l*, air-cavity; *v*, *v*, soft bast. (After Sachs.)

though useful cells. The phloem vessels and parenchyma having very thin walls can be readily distinguished from the thick-walled bast-fibres, and the term soft bast is often used to include the thin-walled elements with cellulose walls. One or more of the elements just mentioned may be wanting, and in the xylem and phloem the parts may be variously arranged. The structure of the bundle not only varies in different plants, but in different parts of the same plant. In ferns, a transverse section of the closed vascular bundle shows the xylem portion in the middle, nearly surrounded by the phloem, which consists chiefly of soft bast. In grasses (fig. 21), and in many other monocotyledons, the xylem placed towards the centre of the stem is V-shaped, and partially encloses the phloem. In a few monocotyledons (*e. g.*, Dracæna) the phloem is completely enclosed. The open bundles of dicotyledons (fig. 22) have the xylem and phloem placed side by side, the xylem inside, the phloem outside, the two parts being separated by the cambium. Such a bundle is called an open collateral bundle, and is characteristic of dicotyledons and gymnosperms. In monocotyledons the vascular bundle of the stem is a closed collateral one, cambium being absent. In a few dicotyledons (*e. g.*, Cucurbitaceæ, Solanáceæ), a second group of phloem is present on the pith side of the xylem (bicollateral bundle). When the xylem is more or less completely surrounded by the phloem (stems of most vascular cryptogams), or *vice-versâ* (a few monocotyledons), the bundle is called concentric. A concentric bundle is, except in Botrychium, closed.

FIG. 22.

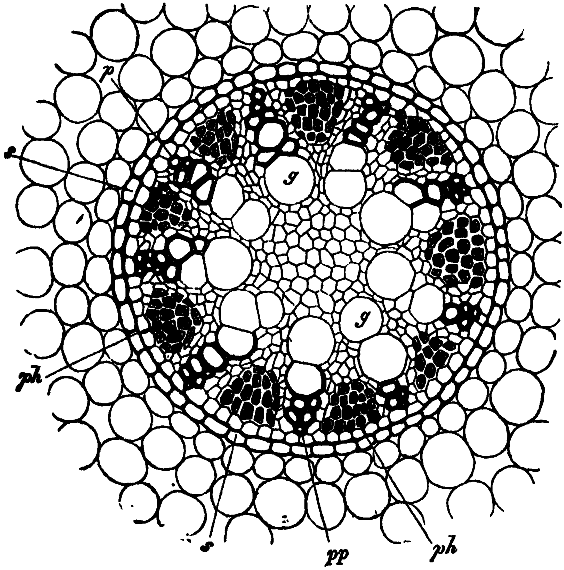


Transverse section of hypocotyledonary portion of stem of *Ricinus communis.*

r, *r*, cortical parenchyma, with bundle sheath; *b*, *s*, the cells containing starch granules; *b*, *y*, phloem; *b*, bast fibres; *y*, soft bast; *c*, cambium, fascicular; *cb*, cambium, interfascicular; *g*, *t*, xylem; *g*, large pitted vessels; *t*, small pitted vessels, with wood prosenchyma and wood parenchyma between them; *m*, pith. (After Sachs.)

In roots the vascular tissue forms a vascular cylinder[1] occupying the axis of the root, and consisting of groups of xylem and phloem lying side by side, but

FIG. 23.



Transverse section of wood of *Acorus calamus*.

s, sheath of fibro-vascular bundles or endodermis, with ground parenchyma of the cortex outside and single layer of cells (pericycle) inside; *p*, bundles of xylem alternating with bundles of phloem, *ph*; *g*, large young vessels of xylem; *pp*, the narrow peripheral vessels. (After Sachs.)

on different radii (radial vascular bundles). The earliest formed vessels of the xylem—the protoxylem—are nearest the periphery (fig. 23, *pp*). The development of the primary xylem is thus centripetal. In the stem, on the other hand, the development is generally centrifugal. The vascular tissue in the root is usually surrounded by two or more less clearly marked layers of cells: the inner or pericycle,[1] and the outer or endodermis.[2] It is from the pericycle in phanerogams, from the endodermis in ferns, that the lateral roots arise endogenously, and opposite the protoxylem.

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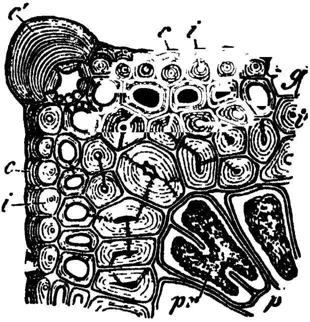
[1] See *note* 5, p. 165.

FIG. 24.



Margin of leaf of *Pinus pinaster*, transverse section (× 800).

c, cuticular layer of outer wall of epidermis; *i*, inner non-cuticularized layer; *c′*, thickened outer wall of marginal cell; *g*, *i″*, hypoderma of thickened cells; *g*, the middle lamella; *i*, the thickening layers; *p*, parenchyma with chlorophyll; *pr*, contracted protoplasmic contents. (After Sachs.)

The Ground or Fundamental Tissues.—The ground or fundamental tissues (fig. 15) include all the internal masses of cells inside the epidermis, remaining over after the fibro-vascular bundles are formed. Very different kinds of cells are met with in the ground tissue, and special modifications generally occur in those parts which are in contact with the cells of the epidermal system, on the one hand, and of the fibro-vascular system on the other. The *hypoderma* (fig. 24) is that portion of the ground tissue in contact with the inner side of the epidermal tissues. The hypoderma often consists of thickened cells, either parenchymatous or prosenchymatous. In the petioles and stem of many dicotyledons the hypoderma consists of rather narrow parenchymatous cells, having the longitudinal walls at their meeting-points very much thickened. This form has been distinguished as collenchyma (fig. 25). In other cases, as in the stems of Equisetum and in the leaves of many pines, the hypoderma is prosenchymatous, the cells being greatly elongated and sclerenchymatous. These cells are often comparable to bast-fibres. The portion next the fibro-vascular bundles is generally modified to form the sheath of the fibro-vascular bundles or endodermis. In palms and grasses the closed bundles are surrounded by a more or less massive sheath (fig. 21) of thick-walled prosenchymatous cells. In Dicotyledons a single layer of cells (fig. 22) forms the endodermis, and it is in contact with the bast portions of the bundles. The rest of the ground tissue, which forms, as it were, a

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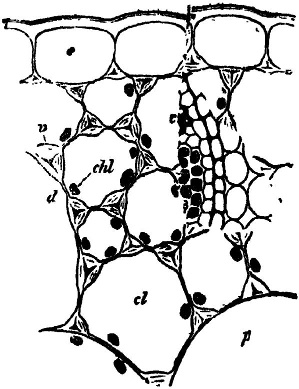
[1] Pericycle has replaced the terms phloem-sheath, and pericambium.

[2] Endodermis is also called bundle-sheath.

FIG. 25.



Transverse section of petiole of *Begonia* (× 550), showing epidermis (*e*), with cuticle and hypoderma, consisting of collenchymatous cells (*cl*) with thickened angles (*v*); *chl*, chlorophyll granules; *p*, parenchyma of intermediate tissue of leaf. (After Sachs.)

padding between the other tissues, is distinguished as the intermediate tissue. Generally this is parenchymatous with intercellular spaces. In the leaf the intermediate tissue is distinguished as the mesophyll, the cells having chlorophyll in their protoplasm, while in roots, stems, and succulent fruits the intermediate tissue is colourless. In different parts of the ground tissue sclerenchymatous cells[1] occur either in groups, as in the flesh of the pear, or as idioblasts as in the leaves of Abies bifida, or in hard strings as in the petioles of Pteris; or massive sclerenchymatous tissue of uniform texture is formed, as in the stones of drupaceous fruits. In dicotyledonous stems, the pith, inner cortical tissue, and the primary medullary rays between the fibro-vascular bundles, all belong to the ground tissue.

Secondary circumferential growth in stems and roots.—Young parts which grow in length also grow in breadth, until all the cells of the part have assumed their full size. The growth of the different tissues in breadth is often not uniform, the external tissues increasing more in circumference than the inner; hence the inner tissues are ruptured, and hollow stems are the result, as in Grasses, Umbelliferæ, &c. In the stems and roots of most Cryptogams and Monocotyledons, the parts grow in breadth, only until all the cells have passed into the permanent condition, no new cells forming in the tissues of the full-grown part. In other cases, as in Dicotyledons and Gymnosperms, a secondary circumferential growth of the stem and root takes place. In the Monocotyledons, Dicotyle

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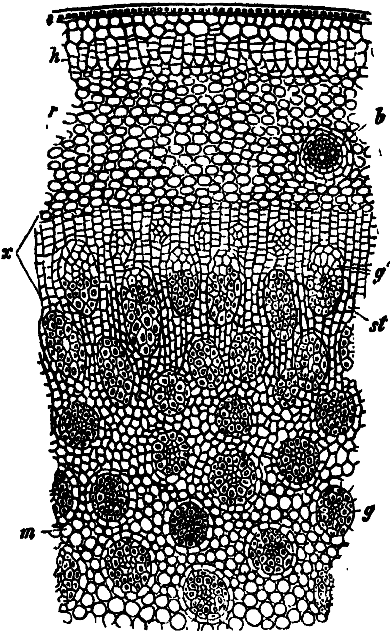
[1] Reference should be made to the larger text books for interesting examples of the mechanical functions of sclerenchyma.

FIG. 26.



Transverse section of stem of *Dracæna*, near ap

e, epidermis; *k*, cork: *r*, cortical portion of ground tissue; *b*, fibro-vascular bundle to leaf; *m*, ground tissue of centre of stem; *g*, fibro-vascular bundles; *x*, meristem zone, developing new fibro-vascular bundles (*g'*) and new ground tissue (*st*). (After Sachs.)

dons, and Gymnosperms we may distinguish thre types of secondary circumferential growth.[1]

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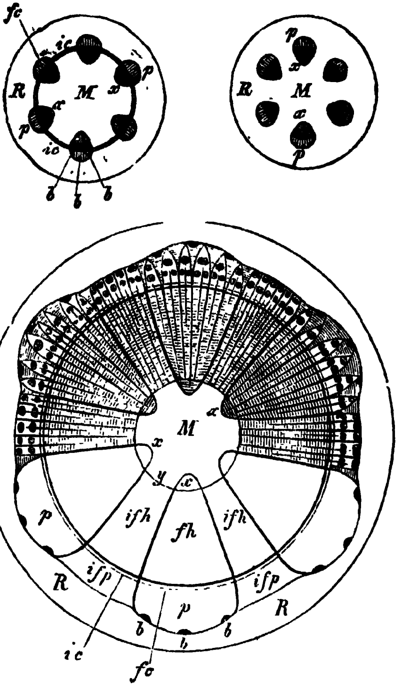
[1] Secondary thickening occurs in two living vascular crypt gams (Isoetes and Botrychium), and was common in foss ones.

FIG. 27.



Diagramatic view of the structure of a dicotyledonous stem with circumferential growth, as seen in transverse section.

A. M, R, ground tissue forming pith (M) and cortex (R), the external ring representing the epidermis. Six fibro-vascular bundles separate,—*x*, the xylem, and *p* the phloem of each bundle.

B, older stem: the bundles now united by cambium ring of fascicular (*fc*) and interfascicular (*ic*) cambium; *b*, *b*, the primary bast-fibres of the phloem.

C, still older stem. By the activity of the cambium new wood and bast have been formed. *fh*, wood formed by fascicular cambium; *ifh*, wood formed by interfascicular cambium; *ifp*, interfascicular phloem; *x*, *y*, medullary sheath. The shaded upper part shows medullary rays. (After Sachs.)

Type I. Tree Liliaceæ (fig. 26). In the Liliaceæ of the genera Aloe, Dracæna, Yucca, Beaucarnia, and Lomatophyllum, the stem increases in diameter by the formation of a meristem layer in the ground tissue which develops new ground tissue and new closed fibro-vascular bundles. The new bundles form an anastomosing net outside the primary bundles. In Dracæna similar circumferential growth occurs in the roots.

Type II.[1] Stems of Gymnosperms and Dicotyledons (fig. 27). The fibro-vascular bundles in the stem are open, with cambium between the xylem and the phloem, the young bundle having vessels, parenchyma, and prosenchyma, as already described (fig. 22). The secondary circumferential growth of the stem entirely alters the constitution of the bundles. Generally the open bundles are arranged in a circle, as seen in a transverse section (fig. 27 A). The bundles are not quite close together, a small quantity of ground tissue remains between them, forming the primary medullary rays. The cells of the ground tissue now form secondary meristem which b[illegible]s over the space between the cambium layer of [illegible]o bundles (fig. 27 B, *ic*). The cambium of the bundle may be distinguished as the fascicular cambium (fig. 27 B, *fc*), and that forming in the ground tissue, the interfascicular cambium, the whole constituting the cambium ring. The cambium ring now separates the ground tissue into two parts, the inner the pith (fig. 27, M), the outer the cortical parenchyma (fig. 27, R). Secondary circumferential growth now begins; the cambium ring developing new cells which form permanent tissue. New permanent tissue is formed on both sides of the cambium layer, new or secondary xylem on the inner side (fig. 27 C, *fh*), new or secondary phloem on the outer or cortical side (fig. 27 C, *p*). The primary xylem projects into the pith and forms the medullary sheath (fig. 27 *x*), while the primary phloem is separated more and more widely from the xylem (fig. 27, *b b b*). The cells formed in the secondary xylem and phloem often differ from those found in the primary parts of the fibro-vascular bundles. Thus in pines the vessels only exist in the medullary sheath or primary xylem, that is, the wood formed from the procambium, while in the secondary xylem we have either tracheides with bordered pits alone, or rarely parenchyma in addition. In most dicotyledonous trees the vessels formed in the secondary xylem have pitted walls, spiral vessels being there absent although present in the primary xylem. The cambium forms secondary medullary rays which run through both xylem and phloem; these increase in number as the stem increases in size. The new wood is arranged in annual rings. Each ring is separated more or less distinctly from the next, and the microscopic examination of the rings shows that the inner part, or that formed in spring, has larger vessels with thinner walls than the part which is formed in the early autumn. The activity of the cambium is uninterrupted during the summer; and, at first, growth is vigorous, the outer tissues not exercising much pressure on the inner. Later in the season, as the wood has increased, considerable pressure is exercised on the new cells, and they become smaller and have thicker walls.[1] When the tree is leafless in winter no growth takes place in the cambium layer, and this causes the well-marked line of demarcation between the different years' growth. The old wood and young wood are also different in appearance, the former, in the centre of the stem, is the *duramen*, the other

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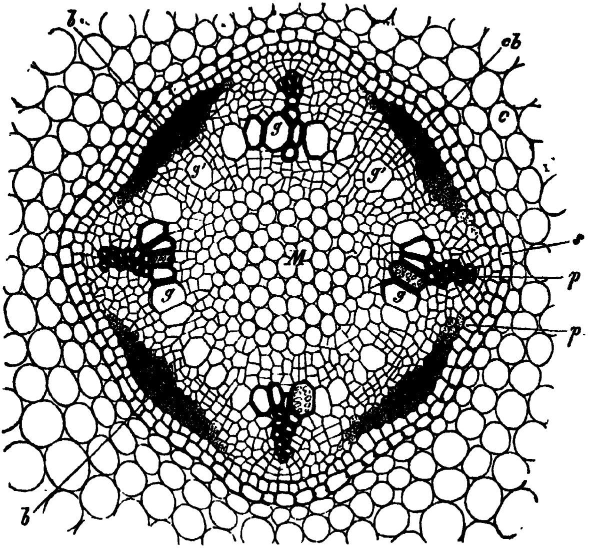
[1] There is almost every possible modification of this type in special cases.

FIG. 28.



Transverse section of root of *Phaseolus*.

M, pith; *s*, endodermis; *c*, cortex; *g'*, vessel of secondary xylem forming; *p*, protoxylem; *pc*, pericycle layer; *b*, primary phloem; *g*, primary xylem, with vessels; *cb*, cambium. (After Sachs.)

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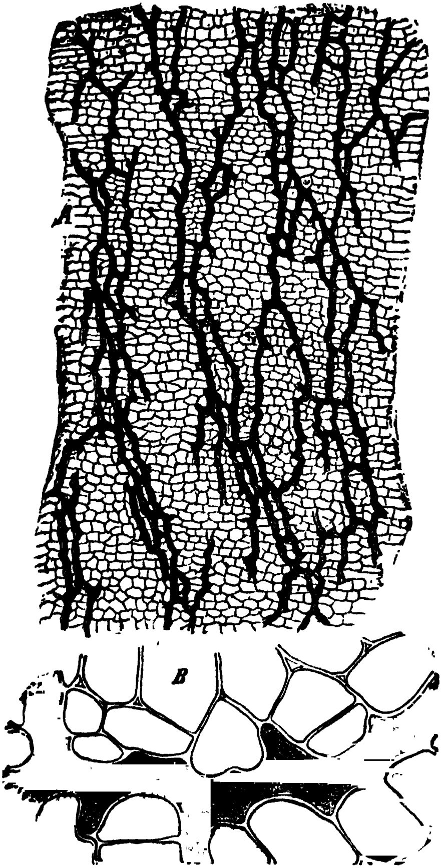
[1] It is now generally thought, the smaller cavities in autumn wood are due to diminution in transpiration current

the *alburnum.* Outside the xylem is the cambium ring of thin-walled cells filled with protoplasm. Further outwards lies the phloem, which is developed annually from the cambium just like the wood, and forms the secondary cortex, so called to distinguish it from the primary cortex formed by the ground tissue. In the phloem the bast-fibres and soft bast are seen arranged in various ways; the bast-fibres or sclerenchyma may, however, be wanting. Often laminæ of bast-fibres are formed which can be separated, as in the lace bark and lime-tree bast. The annual rings are not so evident in the bast as in the wood. External to the phloem in young stems is part of the ground tissue distinguished as the primary cortex, which becomes thrown off in many cases by the formation of cork as already described.

Type III. Roots of Gymnosperms and Dicotyledons (fig. 28). The cambium arises as secondary meristem, from the pith cells on the inner side of the primary phloem, and is completed as an irregular layer on the peripheral side of the primary xylem. Once formed, the root cambium acts, especially opposite the primary phloem, as in the stem of these plants, giving secondary xylem on its inner side, secondary phloem on its outer side. As a result of the secondary thickening, periderm arises, usually from the pericycle, the bulky cortex is thrown off, and the thickening root is thus thinner for a time.

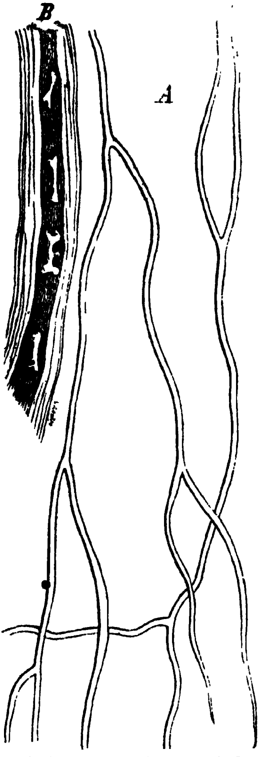
Vessels and Cells with Special Contents.—Distributed among the three systems of tissues of a considerable number of plants, structures are met with which are distinguished by their contents. These

FIG. 29.



A, Section of phloem of root of *Scorzonera hispanica*, showing branching and anastomosing laticiferous vessels.
B, portion of vessel more highly magnified. (After Sachs.)

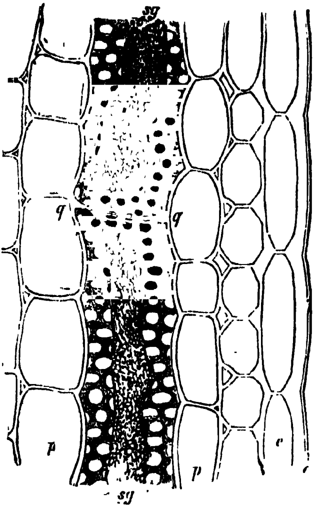
FIG. 30.



A, thick-walled laticiferous cells from *Euphorbia*.

B, more highly magnified portion showing peculiar starch granules. (After Sachs.)

FIG. 31.

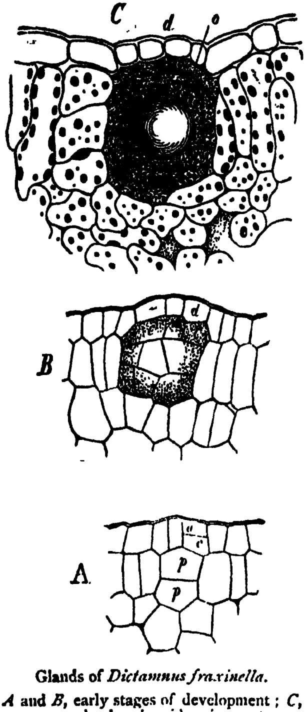


Vesicular vessel in longitudinal section of scale of bulb of onion (*Allium cepa*).

e, epidermis with cuticle (*c*); *p*, parenchyma; *sg*, coagulated contents, contracted to show the porous walls; *q*, *q*, transverse walls. (After Sachs.)

contents are formed, and transported through the plant by vessels or by intercellular spaces; at other times the contents are limited to special cells. Laticiferous vessels (fig. 29) are fusions of straight or branched and anastomosing cells running through the plant. They are to be met with usually throughout the tissues of the plant in which they occur. Examples are to be seen in such plants as the dandelion and other ligulate Compositæ, in Campanulaceæ, Euphorbiaceæ (Manihot), Papaveraceæ, and Araceæ. The contents consist of watery sap[1] in which different substances are dissolved and others suspended, the whole having a colourless or milky appearance, or rarely yellow, red, or blue. In other plants—Moraceæ, Euphorbiaceæ, Asclepiadaceæ, Apocynaceæ—the latex or milky sap is contained in elongated much branched cells (Trichoblasts of Sachs) which run in the ground tissue. These laticiferous cells

FIG. 32.



Glands of *Dictamnus fraxinella.*

A and *B*, early stages of development; *C*, mature gland. *d*, epidermis; *c*, *p*, mother-cells of secreting cells; *o*, drop of ethereal oil. (After Rauter.)

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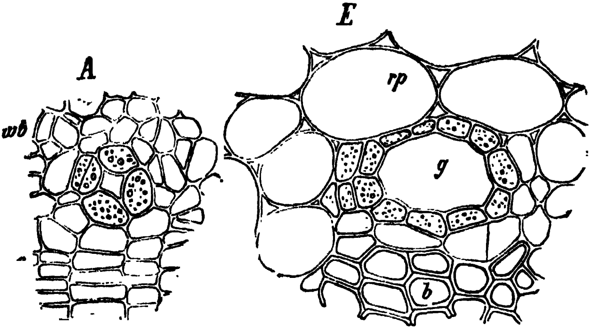
[1] The watery cell-sap is enclosed in a parietal layer of nucleated protoplasm.

are thick-walled in the Euphorbias (fig. 30), and can be tolerably readily separated from the surrounding ground tissue. At other times they are thin-walled, as in the Asclepiadaceæ and Moraceæ. Laticiferous cells and vessels often yield most important substances, of which it will be only necessary to mention India-rubber, gutta-percha, jalap, and opium, to show their great industrial and medicinal value. Vesicular vessels (fig. 31) consist of elongated cells with sieve-like walls arranged in rows, containing a peculiar variety of latex. They occur in the onion and other Monocotyledons, as in the Amaryllidaceæ, and often contain raphides. Glands are cells or aggregations of cells distinguished from those in their neighbourhood by containing resinous, oily, sugary, or fragrant substances. The walls of the cells generally become degenerated (fig. 32) and ultimately dissolved, a cavity filled with the secreted substance being thus formed, as seen in the cavities in the rind of the orange and lemon. In other cases the secretion may be discharged externally, the wall of the cell dissolves, and the secretion remains covered only by the cuticle, which easily ruptures when touched. The nectaries, or honey-secreting glands of flowers, are superficial, and are met with on all parts of the flower and receptacle. The ordinary glands are to be found in almost all the tissues of plants. Glandular hairs are not uncommon, and the bud-glue, or blastocolla, seen on buds such as those of the horse-chestnut, is the product of peculiar hairs called colleteres.

Intercellular spaces, formed by the separation of the walls of cells, often contain secreted materials (fig. 33). The contents are oily in the Compositæ, gum-resin in the Umbelliferæ and ivy, or a clear balsam which hardens into resin in pines. These turpentine canals are well seen in the conifers. The intercellular resin and gum canals are limited to a few natural families of plants, and may be seen cut across in a transverse section of the stem or leaf.

FIG. 33.

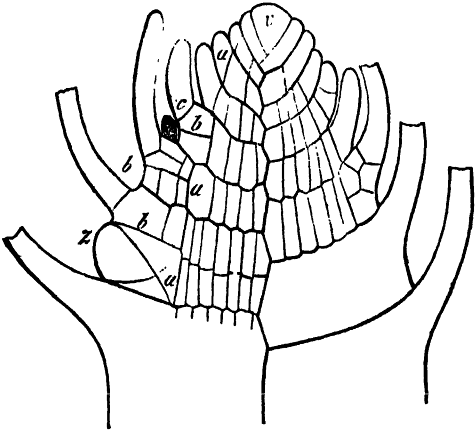


Transverse sections of young stem of ivy (*Hedera Helix*, × 800).
A, young intercellular gum-canal, surrounded by four cells. *c*, cambium ; *wb*, soft bast.
E, fully developed canal (*g*); *b*, bast ; *rp*, cortical parenchyma. (After Sachs.)

Protomeristem and Apical Cell.—The apex or growing end of the root or stem is called the growing point, or vegetative cone, from its usually conical form. In the root it is covered by a cap of cells, the pileorhiza, while the apex of the stem is not so covered but is concealed and protected by the young leaves of the bud. The growing point consists entirely of protomeristem, the cells being capable of dividing.

They are filled with protoplasm, are thin-walled with no intercellular spaces, and are not yet differentiated into permanent tissue. Some organs, as most leaves, consist at first of protomeristem, which gradually passes entirely into permanent tissue; and as no meristem remains, the part grows to a *definite* size and afterwards experiences no further alteration. In roots and stems some meristem always remains at the apex, hence the growth in length is *indefinite*. In most Cryptogams, the protomeristem is formed by the division of a single cell, called the apical cell (fig. 34) at the growing point. In general, it is a large cell,

FIG. 34.

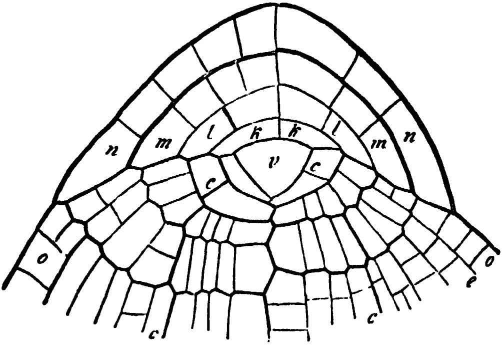


Apex of stem of moss (*Fontinalis antipyretica*), longitudinal section.

v, apical cell, forming segments (3 rows), each segment divided into an outer segment (*a*) and an inner—the former developes cortex of the stem and a leaf, the latter the inner tissue of the stem; *z*, apical cell of lateral leaf-forming shoot, arising below a leaf; *c*, first cell of leaf; *b*, cells forming cortex. (After Leitgeb.)

which divides into two daughter-cells, one of the two new cells enlarging and becoming a new apical cell; the other, the segment cell, divides still further, forming the protomeristem, from which the permanent tissue is developed. The apical cell divides in different ways, as transversely, obliquely, in two rows, or in three rows. While the tissues of the Cryptogams thus generally owe their origin to a definite apical cell, the tissues of the higher plants have, as a rule, no such cell. Their apex is stratified, *i.e.* consists of several layers of cells (more or less clearly marked), which divide to form the mass of protomeristem. In the case of roots, the apical cell (fig. 35) forms the root-cap by segments cut off from the front; and in a similar way in the higher plants the apical group of

FIG. 35.



Longitudinal section of apex of root of *Pteris hastata.*

v, apical cell; *c*, *o*, *e*, the tissues of the root—*o*, the epidermis; *e*, the cortical tissue; and *c*, the primary fibro-vascular bundles; *k*, *l*, *m*, *n*, the tissue of the root-cap. (After Naegeli and Leitgeb.)

cells forms the cap covering the growing point. In the stems of plants segments are not formed in front of the apical cell, or apical group of cells, as there no structure resembling the pileorhiza of the root is to be met with.

CHAPTER III.

THE EXTERNAL CONFORMATION OF PLANTS.

Parts of the Plant Body.—The body of one of the higher plants consists of a number of organs performing different functions, and popularly known as stems, leaves, flowers, seeds, and the like.[1] It is the province of the department of biological research called physiology to investigate the functions of these various organs. If, however, instead of taking into consideration the functions of the organs, we examine all the organs of plants merely as portions of the plant-body, then we obtain a knowledge of the morphology of the parts. In the morphological study of the parts of plants we have to consider the relative positions of these parts, their place, time and mode of formation, the manner and nature of their growth, and the ultimate size they attain. This we can do without considering the functions of the parts. All the organs of the higher plants, notwithstanding the very varied functions which they discharge, can be referred to a few type-parts, namely, the root, stem or caulome, leaf or phyllome, and hair or trichome. In the lower plants the plant-body is a thallus or thallome. These typical parts become modified and adapted to perform many functions. Thus phyllomes form many organs, as scale-leaves, foliage-leaves, and floral-leaves; while the organs known as tendrils may be morphologically phyllomes or caulomes.

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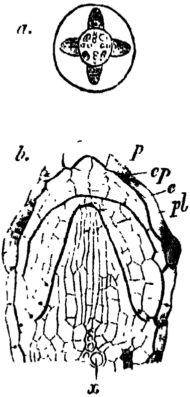
[1] See *note* 2, page 164.

The different parts of the plant are all in organic connection one with the other. Most of the parts are developed laterally from other parts, the exception being the main axis of the plant, which arises directly from the embryo, and thus from the fertilised germinal cell. Stems, leaves, and hairs develop as lateral formations on the main stem, leaves form laterally on branches, and hairs on stems, branches, or leaves. So roots develop lateral rootlets, or we have rootlets developing from stems, or even from the petioles of leaves. The different parts of plants are thus all developed laterally one from the other, and equivalent parts may have a different origin—a root may arise from another root, or from a stem, while a stem may produce branches, leaves, or hairs. Lateral parts are distinguished as normal and adventitious. Such parts, when normal, always have a definite order of succession on the part subtending them. Thus the youngest rootlets, branches, or leaves, are always nearest the growing point or apex of the subtending root or stem. The older the parts are, the further removed from the growing part they become. This mode of development, in which the youngest parts are nearest the apex or growing point of the stem or root, is called *acropetal.* The position of the parts on the axis will show their order of succession in time. When parts are not developed acropetally, they are distinguished as adventitious; roots and buds being adventitious when they are intercalated at a later period between those formed acropetally.

FIG. 36.



a. Diagram of cross-section of a tetrarch dicotyledonous root, showing four lateral endogenous roots arising opposite the primary xylem groups of the parent root.

b. Origin of a lateral root, magnified. *x*, xylem of parent root; *pl*, plerome (body) of lateral root; *c*, its cortex; *ep*, epidermis and root-cap; *p*, *digestive pouch*, derived from endodermis of main root; by secretion of ferment, &c., helps the lateral root in outward course. (After Van Tieghem and Douliot.)

Lateral parts may be produced singly, or two or more may be formed at the same distance from the growing point. When two parts are formed, they are called opposite, when more than two a whorl. It is not necessary that the parts forming a whorl should all appear at the same time; they sometimes appear simultaneously, sometimes in succession.

Lateral parts may either have an exogenous (superficial) mode of origin, or an endogenous (deep-seated) origin. Thus leaves are developed from the outer cells of the stem, and are therefore exogenous; while roots have a deep-seated origin, they have to break through the external tissues, and are endogenous. These modes of origin are of great importance morphologically.

Root.—Popularly a root may be any part formed underground, but morphologically it has a very definite signification. Roots are not met with in Thallophytes and Bryophytes, but are present as a rule in all plants with fibro-vascular bundles. Psilotum, Salvinia, Wolffia, are examples of rootless vascular plants. The characters of roots are: *first*, that they develop endogenously (fig. 36), they have a deep-seated origin, either from the pericambium layer of roots (figs. 23 and 28 *p, c*), or from the outer part of the phloem in stems, and work through the superficial tissues, the epidermis and cortical layers of the main root or stem being absorbed by the activity of the *digestive pouch*. *Secondly*, the root does not develop leaves acropetally; and *thirdly*, the growing point of the root is covered by a special structure, developed in the higher cryptogams from the apical cell, and in phanerogams chiefly from the dermatogen covering the growing point (fig. 35). This special structure is called the root-cap or pileorhiza. The new cells of the pileorhiza are formed internally, the external cells being constantly thrown off as new ones form. By these three characters the morphological part called the root can be readily distinguished.

Many plants develop a large main or tap-root, which is produced by the growth of the root formed in the young embryo plant at the lower end of the stem. In the bean and most dicotyledons it is greatly developed, giving off numerous lateral rootlets in an acropetal manner. In most monocotyledons the main root never attains any great development, and the masses of fibrous roots in such plants as grasses develop adventitiously from the lower end of the stem. All normal roots in Phanerogams arise from the pericycle externally to the first groups of xylem in the fibro-vascular body, rarely external to the phloem (Umbelliferæ, grasses). Hence the roots are arranged in long rows, the number of rows corresponding to the number of xylem masses. Adventitious roots appear later in an irregular manner, and generally more or less obscure the original arrangement.

FIG. 37.

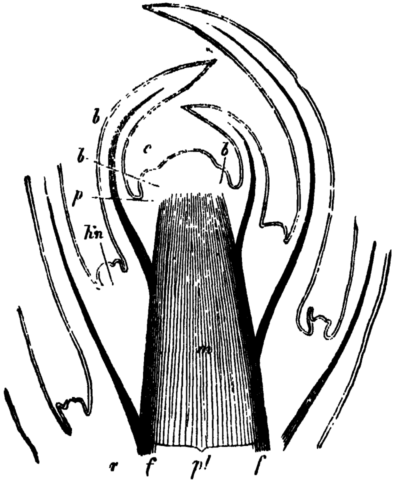


Diagram of a longitudinal section of the apex of the stem of a dicotyledonous plant.

m, pith ; *f*, fibro-vascular bundles, both developed from the plerome (*pl*), the bundles sending branches to the leaves ; *r*, cortical tissue ; *e*, epidermis ; *b*, *b*, young leaves, two showing their origin from protomeristem (*p*) ; *kn*, axillary bud. (After Prantl.)

In grasses and other plants the end of the root in the embryo plant is covered by a mass of tissue through which the young root must force its way.

The tissue surrounds the base of the root as a sort of sheath, to which the name of coleorhiza has been applied.

Roots vary much in form and function. Their primary function is to fix the plant in the soil, and to take up water with mineral substances[1] in solution; hence the fibrous or narrow cylindrical form may be looked upon as the type. Many roots serve as reservoirs of nutrient materials, and thus become enlarged and thickened, either regularly or irregularly, by subsequent growth. As examples we may take the fusiform succulent root of the carrot, or the tuberous root of the dahlia. Aërial roots are special modifications. They occur abundantly on the stems of tree-ferns, and in orchids and aroids serve to fasten the plants to the stems of trees. The adventitious roots of the ivy are root-tendrils fixing the stem to a solid support. In parasitic plants, such as the dodder, peculiar sucker roots are met with, which penetrate into the tissues of the host from which the plant derives its nourishment.

Stem, Leaves, and Leaf-bearing Axis.—That part of the plant which developes leaves as lateral appendages near its apex is called the stem, axis, or caulome, while the term shoot is used to distinguish the stem with its leaves. The stem or caulome may be defined as the part which develops the leaves (fig. 37), while leaves have certain characters in relation to the stem. Thus leaves always originate in an acropetal order, and are therefore always normal as distinguished from adventitious. Secondly, leaves are always exogenous formations, arising from the superficial tissues of the protomeristem, and the tissues of the leaf are directly continuous with those of the stem (figs. 37 and 34). Lastly, the leaf always assumes a form different from that of the axis by which it is produced. Leaves originate in acropetal order close to the growing point of the stem. At first the leaves are all crowded together, helping to form the buds, the portions of stem between the individual leaves elongating when the buds open. In many plants the portions of stem between the leaves remain undeveloped, and a rosette of leaves is thus formed, as in Plantago, Sempervivum, and in most flowers. As a rule the portions of stem between the leaves become elongated. The lengthened portions are called the internodes, while the boundary between them where the leaves come off is called the node. The stem thus consists of nodes and internodes, the leaves being attached or inserted at the node, the centre of the base of the leaf being the point of insertion.

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[1] The root-hairs, outgrown epidermal cells, are the chief absorbing agents.

The tissues of the stem and leaf are continuous, the different tissues, epidermal, fibro-vascular, and ground, running uninterruptedly from the one to the other (fig. 36). The fibro-vascular bundles when first produced generally bend out into the leaves forming the common bundles, *i. e.* common to stem and leaf. In other cases the stem possesses special bundles, the cauline bundles, to which the bundles coming from the leaves may become attached laterally.

The growing end of the shoot differs from the apex of the root in having no pileorhiza, but developing leaves instead. These leaves are at first crowded together and form the bud. The end of the axis is quite hidden and protected by the young leaves which bend over the apex, and grow more rapidly than the axis producing them. When the bud opens the leaves enlarge and the internodes elongate. The mode of arrangement of the leaves in the bud is called the vernation, or sometimes the præfoliation. Flower-buds and flowers are merely buds and shoots in which the leaves are specially modified. The leaves in the flower-bud are arranged like those of the leaf-buds, but the term æstivation or præfloration has been applied to their arrangement.

Shoots are either normal or adventitious. All normal shoots (except the axis of the embryo) arise by branching. With the exception of dichotomous branching, the branches always have a definite relation to the leaves. Thus in phanerogams the branches are axillary, one bud being produced in the axil or angle between the leaf and the next upper internode. In the bulbs of Muscari, the stem of Aristolochia Sipho, and in Lonicera, several buds are formed in the axil of the leaf. In cryptogams, lateral shoots may be produced near or below a leaf, but the shoots are not axillary. In dichotomous branching, the branches may form near leaves, and look at first sight as if axillary. Adventitious shoots are of common occurrence. They are not acropetally developed, as axillary buds must necessarily be, but appear irregularly from many parts of plants. They occur on the roots of many of our trees, as the poplar. They also develop from leaves, as in the Bryophyllum and many ferns; or from the petioles of leaves, as in Aspidium Filixmas. Normal or adventitious buds may become detached from the parent plant, and form new plants by non-sexual reproduction. Such bulbils or bulblets occur on Lilium bulbiferum, Dentaria bulbifer, Asplenium decussatum, and the inflorescence of Allium. Mosses and other cryptogams produce very much simpler structures, the gemmæ, which are of importance in the non-sexual reproduction of these plants.

Stem or Caulome.—Stems are generally more or less elongated structures, cylindrical or prismatic in form, and serve primarily as organs of support to the leaves and flowers, and channels for the conveyance of nutrient matter in solution from the soil. In other cases the stem acts as a reservoir of nutrient materials and becomes much thickened. The nature of the stem varies with the duration of the plant, being in some plants a soft herbaceous axis or stalk of annual duration, in others a woody stem growing in thickness and giving off branches. When thickened and shortened and developed underground, we have the tubers of the potato, or Jerusalem artichoke. When the basal portions of the leaves are largely developed and the axis short, the bulb of the onion or tulip is produced. The rhizome is an elongated, often thickened, perennial underground stem, as in the Solomon's seal and anemone, while the corm (Colchicum) is a short thick stem which gives off a bud, the older part dying when the young bud reaches maturity. Stolons (strawberry) are annual stems given off at the base of a plant; they generally develop scale leaves and form buds which root and render the plant perennial. Special modifications of stems occur, as the phylloid caulodes or cladodes, the flattened leaf-like shoots of Ruscus. Stem-tendrils are met with in the vine and passion-flower, while stem-spines or thorns occur in the sloe or hawthorn. Climbing or voluble stems, too weak to support the weight of their foliage, and thus requiring to twine round some solid object, are seen in the hop, scarlet runner, and convolvulus. The stems of cacti are peculiar and worthy of notice from their special form and growth, and on account of their performing the function of leaves.

Leaf, or Phyllome.—Leaves are generally limited in their growth, and are flat expansions, divisible into two similar halves by a vertical plane running through the apex and point of insertion. In some cases abnormal forms of leaves occur. The leaf may not be limited in its growth, but elongate at the apex somewhat like a stem, or the form may be peculiar, cylindrical, prismatic, or tubular, or the leaf may not be symmetrical, as in the Begonias. The under or outer surface of the leaf generally differs from the upper or inner in colour, structure, and in the nature and appendages of the epidermis. Torsion may occur, as in Alstrœmeria, or the leaf may be flattened laterally in its upper part, as in the Iris.

Different regions of the stem produce, in the higher plants, different kinds of leaves. Excluding the leaves forming the flower, we have three kinds occupying different positions on the stem. At the lowest parts of the stem or base of a shoot we have scale-leaves, or phyllades; at the upper part below the flowers are the bracts, and between the two the ordinary foliage leaves are developed. Scale leaves are met with on underground stems as on bulbs and on the tubers of the potato. Cotyledons are also scale-leaves, but in many plants they develop chlorophyll and act as ordinary foliage leaves, at least for some time. The bud-scales at the base of each shoot are also scale-leaves. In plants which contain no chlorophyll (Orobanche, &c.), the leaves are reduced to scales. Scale-leaves have in general very definite characters. Their outline is simple, and they never develop prominent veins; they contain little or no chlorophyll, and generally serve to protect other parts. The foliage leaves are the chief organs of assimilation, and develop large quantities of chlorophyll, their form and appearance being very varied. The bracts belong to the upper or flowering region of the stem, and are generally very much smaller than foliage leaves, are stalkless or sessile, with a narrow base of insertion, and are sometimes green, often brightly coloured or white. The floral leaves consist of four series or cycles called calyx-leaves or sepals, corolla-leaves or petals, leaves of the andrœcium or stamens, and leaves of the gynœcium or carpels.

The tissues of the leaf are continuous with those of the stem—the epidermis covering the upper and under surface, the ground tissue or mesophyll which is rich in chlorophyll continuous with the ground tissue of the stem, and the fibro-vascular bundles ramifying in the mesophyll forming the veins of the leaf, generally prominent, at least on the under side. The course of the veins or the venation is characteristic of certain of the classes of plants. Thus the monocotyledons have narrow leaves with parallel veins, connected by small cross-veins, while the dicotyledons have only a few veins entering the leaf, but these branch and anastomose, forming the reticulated venation in the blade. According to the mode of branching of the veins the venation is either pinnate like a feather, as in the beech or elm, or palmate, where the veins divide at the base as in the ivy and sycamore.

The leaf can be divided into certain parts or regions, one or more of which may be wanting. In the most perfectly developed leaves, as in those of palms, aroids, and umbellifers, the leaf can be divided into three parts, the sheath, the stalk or petiole, and the blade or lamina. In grasses the petiole is wanting, and the leaf is reduced to the sheath and blade. In most dicotyledons the sheath is absent, and the stalk and blade only occur, while in other plants, as in the tobacco or Lilium bulbiferum, the blade only is present. The blade is the flat expansion which narrows into the cylindrical or prismatic petiole, while the sheath surrounds the stem like a split or entire tube, and often receives special names.

Many different terms are applied to the forms of leaves, nature of apex, base, and margin, and also to the mode in which they are related to the stem, all of which are of importance in descriptive botany, and can be met with in any flora. If the blade of the leaf is in one piece the leaf is simple, if cut up into jointed pieces the leaf is compound. The leaf is lobed when cut slightly, cleft when cut to the middle of the lamina, partite when cut beyond the middle, compound when the lamina is cut into several portions.

The divisions indicate branching of the leaf, and the different forms pass gradually one into the other. As the branching follows the arrangement of the veins, we have two series of forms depending on the pinnate and palmate venation. Thus we have pinnately-lobed, pinnatifid, pinnatipartite, and pinnate (compound) leaves. In the same way we have palmately-lobed, palmatifid, palmatipartite, and palmate (compound) leaves. In many cases the divisions are cut a second or third time, and in the palmate forms of compound leaves the number of leaflets is generally taken into consideration, giving us the ternate, quaternate, quinate, and digitate forms.

Branches of the leaf close to its insertion are distinguished as stipules.[1] They generally occur in pairs, one at each side at the base of the leaf. They are free in the willow or pea, adnate to the petiole in the rose, inserted together opposite the leaf in Astragalus, and interpetiolar in the Cinchona. The ligule is a peculiar outgrowth in the upper or inner surface of the leaf.. It is seen in the grasses at the point of junction of the blade and sheath. The corona of Narcissus, Lychnis, and the Boragineæ, consists of ligules developed on the petals.

Special modifications of leaves are frequently met with. Thus there are leaf tendrils common in the Leguminosæ, the whole or only a part of the leaf becoming converted into a tendril. Flattened petioles or phyllodes often replace the compound leaves in some species of Acacia. Leaf spines are met with in the barberry, and the modified stipules of Robinia pseudacacia. In some cases the blade is developed into a pitcher, as in Nepenthes and Sarracenia. These latter modifications are connected with the absorption of nitrogen by the plant; animal matter being digested and absorbed in Nepenthes, or putrescent matters absorbed by Sarracenia.

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[1] Stipules are simply more or less leaf-like expansions of the base of the leaf, as a rule.

Hair or Trichome.—The hair is an outgrowth of a single epidermal cell. It may remain simple, but more frequently becomes multicellular (fig. 17). By thus defining a hair, many different organs can be shown to be morphologically trichomes. Thus the root-hairs of mosses and hymenophyllums, while performing the functions of roots, are trichomes. The sporangia of ferns, which are the non-sexual reproductive organs, are also modified hairs, or better, structures *sui generis.*[1] Prickles or aculei occurring on some brambles and roses, differ from true hairs in their originating from the epidermis, and one or more cells below it. Sachs calls them emergences. Rarely, as in the prickles of the fruit of the horse-chestnut and Datura, a fibro-vascular bundle enters the emergence. They resemble spines in being sharp pointed structures, but differ in their arrangement and in their not being either modified stems or leaves. Hairs vary much in their structure, and many terms are given to the different varieties of surface caused by the presence or absence of hairs.

Thallus or Thallome.—In the lower plants there is no separation into stem, leaf, and root, while in the lowest forms a single cell only is to be met with.

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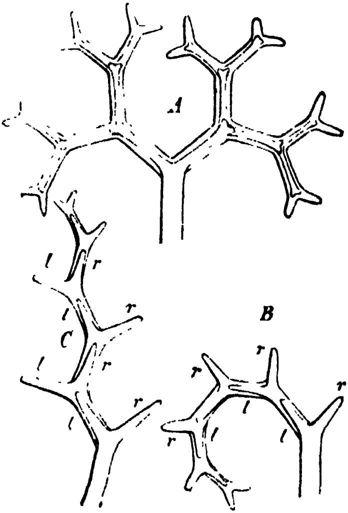
[1] Represented in Phanerogams by the pollen-sacs and ovules.

The body of these lower plants is called a thallus or thallome, which may be unicellular or multicellular. In both cases the thallome may be differentiated into parts resembling root, stem, and leaf,[1] but differing in structure from the parts so named in the higher plants, as in the unicellular Caulerpa, and multicellular Fucus. The thallome is met with in the thallophytes, and in many of the liverworts. In the early stage of the development of the moss, a thallus-like protonema is formed, which gives rise to numerous buds. The earliest stage in the fern, known as the prothallus, which develops the reproductive organs, is also morphologically a thallome.

FIG. 38.



Diagrams of dichotomous branching.

A, normal dichotomy, the fork-branches equally developed, and becoming the podia of new dichotomies.
B, Bostrychoid dichotomy, one fork-branch only becoming the podium of a new dichotomy; in this case the left, *l*.
C, cicinnal dichotomy; one fork branch, alternately left (*l*) and right (*r*), becoming the podium of a new dichotomy. *B* and *C* are sympodial arrangements. (After Sachs.)

Development of Branches.—Branching is the lateral development of similar parts. Thus a root branches and produces rootlets, a stem branches, or a leaf and hair may branch. The lateral development of dissimilar parts is not branching, as when a stem produces leaves or hairs. By branching, systems of branches are formed in which we can distinguish the

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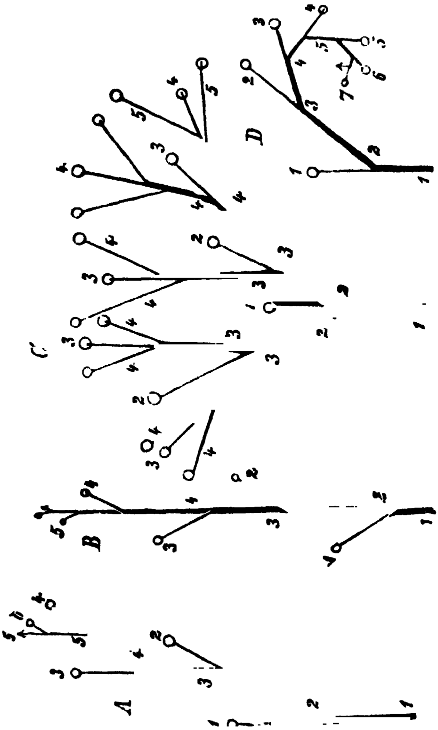
[1] See *note* 3, page 164.

FIG. 39.



Diagrams of sympodial varieties of monopodial branching. *A* and *B*, cicinnal monopodia. *C*, dichasium, or false dichotomy. *D*, bostrychoid monopodium. The axes are numbered in succession from 1 to 7. (After Sachs.)

axis (foot or podium), and the branches. These systems of branching can be referred to two chief types, the dichotomous and the monopodial.

Dichotomous branching (fig. 38).—In dichotomy the end of a part ceases to grow in length, and at the apex two new parts appear which at first usually develop equally. We have thus the foot or podium and the two fork-branches, both of which may become the podium of a new dichotomy (fig. 38, A). In some cases the two branches are equally developed, but in others the system becomes sympodial, one branch becoming more strongly developed than the other. By the unequal growth, the podia of successive parts appear as an apparent main axis, the pseudo-axis or the sympodium, while slender fork-branches appear as lateral branches, which at first sight might be confounded with the monopodial method of branching. In sympodial dichotomies the sympodium consists either of the fork-branches of the same side, right or left, the bostrychoid (helicoid) dichotomy (fig. 38, B), as seen in the leaf of Adiantum pedatum, or the branches are alternately right and left, the cicinnal (scorpioid) dichotomy (fig. 38, C).

Monopodial branching (fig. 39).—When the axis produces lateral branches in acropetal order, and forms a single common foot or podium for all the lateral branches, the system is called monopodial. Each branch of the monopodium may again branch in a monopodial manner. Monopodial branching may be either botryoid (racemose), or cymose. In the former the main axis is more strongly developed than the lateral ones, while in the cymose arrangements the lateral axes soon begin to develop more strongly than the main one. There are two varieties (*a*) with no pseudo-axis, two or more equally strong lateral axes forming, the mother axis ceasing to grow; the dichasium or biparous (fig. 39, C) and the pleiochasium or multiparous cyme; (*b*) with a pseudo-axis, the sympodial arrangements of monopodia which are either bostrychoid (helicoid) (fig. 39, D), or cicinnal (scorpioid) (fig. 39, A, B). The modes of branching here described refer not only to stems, but also to the thallus, roots, leaves, and hairs.

Position of Lateral Parts on a common Axis.—All normal lateral parts, those developed acropetally, have a definite position on the surface of the part producing them. Thus rootlets have a definite relation to the main root; branches and leaves have a definite position on the subtending axis. The positions are not mathematically exact, and as displacements occur during growth, the arrangements are sometimes rather obscure. The arrangement of leaves on the stem, or phyllotaxis, may be taken to illustrate the position of all lateral parts. Leaves may be developed in verticils or whorls, or be opposite, two or more forming at the same transverse zone of the stem, or the leaves may be inserted singly. When the leaves are in whorls, the whole of the leaves may appear simultaneously, or they may develop in succession. In some cases false whorls are produced by the suppression of the internodes, a condition met with in the upper leaves of Lilium bulbiferum. When the leaves are placed singly at different parts of the stem they have a certain divergence. If a line be drawn through the apex and the point of insertion of one leaf, and another through the apex and point of insertion of the next, an angle will be formed called the angle of divergence. This angle varies in different plants. If it be two right angles, the angle of divergence will equal one half the circumference of the stem; if one right angle, one quarter the circumference. The angle of divergence measures the lateral distance between any two consecutive leaves, and we may express the distance either by giving the number of degrees, or more conveniently by a fraction. Thus we may use 90° or the fraction $\frac{1}{4}$; 180° or the fraction $\frac{1}{2}$. If we number the leaves in order as they are acropetally developed, and always proceed in one direction, we can draw a spiral line round the stem, which passes through the insertions of all the leaves in the order in which they have been developed. This spiral line is called the generating spiral. In fractions above $\frac{1}{2}$ the generating spiral may be traced in a longer or shorter way, *i. e.*

FIG. 40.

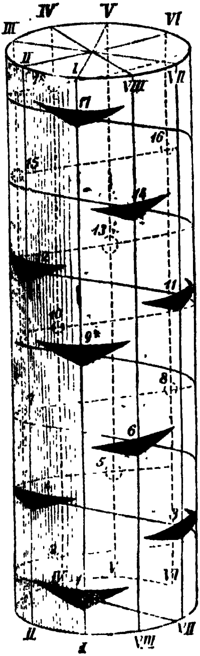


Diagram of a stem showing the $\frac{3}{8}$ phyllotaxis.

The leaves are in 8 orthostichies *I* to *VIII*. The generating spiral is shown following the shortest course from leaf to leaf, numbered in succession from 1 to 17. In passing from leaf 1 to leaf 9, 3 turns round the stem pass 8 leaves, the 9th being above the first. (After Prantl.)

either from left to right or from right to left. Thus, if we find the arrangement to be, say $\frac{3}{8}$, three turns round the stem pass eight leaves, and find the ninth leaf above the first; by reversing the spiral we have to pass more frequently round the stem, making five turns when passing through the eight leaves. In the longer way then the fraction will be $\frac{5}{8}$. In some cases

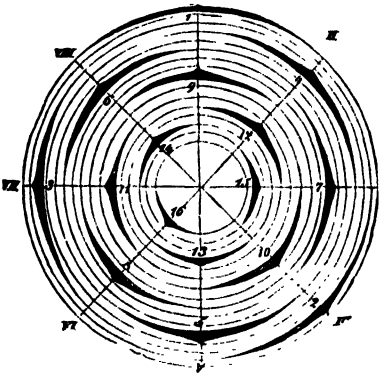


Diagram of stem with $\frac{3}{8}$ phyllotaxis.
The orthostiches numbered *I* to *VIII*, the leaves 1 to 16.
(After Sachs.

the fraction is constant, and the divergence does not vary; but we may have variations or a rhythmal change, as $\frac{2}{5}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{1}{3}$, and so on. If we take the $\frac{3}{8}$ arrangement (figs. 40 and 41), we notice the ninth leaf above the first. Leaves 1 and 9 stand in the same plane. A straight line rising perpendicularly from No. 1 would pass through No. 9. These leaves are superposed, and the line cutting the superposed leaves is called an orthostiche. The collective leaves between 1 and 9 form a cycle. The number of leaves in the cycle will determine the number of orthostiches. Thus in the fraction $\frac{3}{8}$ there are eight orthostiches. The number of orthostiches is always indicated by the denominator of the fraction, while the number of turns required to complete the cycle is expressed by the numerator. Eight orthostiches may occur with a fraction other than $\frac{3}{8}$. Thus in the Herb Paris (*Paris quadrifolia*), (fig. 42), there are eight orthostiches, but the fraction is $\frac{1}{4}$. There are four foliage leaves. The external floral leaves have the same arrangement, but alternate with leaves below and above. Hence the leaves of the first and third whorl are superposed, or in the same orthostiche; the leaves of the second alternating with them. In opposite and decussate leaves there are four orthostiches, and the fraction is $\frac{1}{2}$; while in other cases there are two orthostiches, the fraction being $\frac{1}{2}$, and the leaves either alternate or are opposite, *i. e.* in a whorl of two.

Fig. 42.

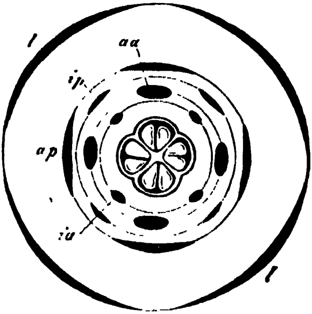


Diagram of flowering stem of *Paris quadrifolia.*

l, leaves; *ap*, outer parts of perianth; *ip*, inner part of perianth; *aa*, outer whorl of stamens; *ia*, inner whorl of stamens. Gynœcium of 4 carpels in centre, 4 parts in each whorl, alternating, hence 8 orthostiches. The outer stamens *aa* and carpels are *superposed* to the outer parts of perianth, and *alternate* with the leaves *l*, inner parts of perianth *ip*, and inner whorl of stamens, these being in their turn superposed to one another. (After Sachs.)

When the leaves on a shoot are closely crowded together, it is often very difficult to see the generating spiral. In the young shoots and cones of pines, the secondary spirals or parastiches are well marked. By counting the secondary spirals to the right and to the left, the generating spiral can be determined.

In some plants no generating spiral can be traced, as in the Marsileas. In others, the angle of divergence alters so frequently that no orthostiches are present (*Fritillaria imperialis*). The most common divergences are those expressed by the fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, $\frac{13}{34}$, and so on. But other series exist, as $\frac{1}{4}$, $\frac{2}{7}$, $\frac{2}{9}$, &c. It must be borne constantly in mind that the position of the leaf is not so exact as the use of the fraction would naturally lead us to suppose.

Apparent exceptions to general laws, caused by displacement, adhesion, and abortion, are common among the leaves, and shoots of monocotyledons and dicotyledons. Thus the beginner finds it difficult to understand the construction of the flower of an orchis or rose, the nature of the fig, and of the inflorescence of Solanaceæ. The study of the development of such structures shows that at first the ordinary laws of development are followed; but at a comparatively late stage deviations are caused by certain parts ceasing to grow while others develop in excess. Displacement and adhesion generally occur together; and sometimes we have displacement, adhesion, and abortion concurring to render the structures very complex.

Alternation of Generations.—When plants have continued to grow for some time, and have assumed a definite external conformation and internal structure, single cells are detached which sooner or later form new plants. These new plants may either be like or unlike the parent. The production of reproductive cells may either be by a sexual or non-sexual process of reproduction. In some cases the successive generations, whether produced sexually or non-sexually, are similar, and produce similar reproductive cells; but in most plants the generations which proceed from one another are dissimilar, and produce different kinds of reproductive cells, sexual or non sexual. This alternation of generations forms a very marked character in many plants; as, for example, in the ferns.

The fern-plant forms, in the end, on its leaves, the spores.[1] These spores become set free, germinate, and produce the flattened green expansion or prothallus. The prothallus produces the sexual organs. From the fertilised ovum or oosperm a new fern-plant arises. Thus in a fern the order of succession is prothallus, sexual organs, oosperm, fern-plant, spores, prothallus. The prothallus with its sexual organs is one generation (oophyte or gametophyte), the fern-plant, from oosperm to spores is the second generation (sporophyte).[2] An alternation of generations, comparable to this, is traceable more or less clearly in all higher plants; not so clearly, when at all, in most thallophytes.

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[1] In the sporangia.

[2] Apogamy is the production of the sporophyte from the gametophyte without the intervention of the sexual organs; apospory the production of the gametophyte from the sporophyte without the help of the spores. Both phenomena are to be met with, exceptionally, in ferns.

PHYSIOLOGY OF PLANTS.

CHAPTER IV.

THE NUTRITION OF PLANTS.

Composition of Plants.—All plants contain a considerable quantity of water, the actual proportion depending partly on the nature of the part, and also on the period of the year. Thus, in the stems and leaves of plants there is on an average about 70 per cent. of water. In water-plants and some fruits and roots the quantity of water is greater, amounting to 90 per cent. In seeds the protoplasm is dense, and only about 12 per cent. of water is present. When germination takes place, the quantity of water rapidly increases. In the buds of plants in spring there is very little water, but as soon as growth begins and the buds expand, the quantity of water rapidly increases. It is on account of the increase of water that spring frosts injure opening buds, which have resisted the severe cold of the earlier part of the season. The water in plants can be removed by drying the part in a water oven at a temperature not exceeding 100° Cent., and the dry organic matter is left behind.

Organic matters are those substances left behind after the water has been expelled, consisting of the materials forming the cell-walls and cell-contents, as cellulose, starch, protoplasm, &c. These organic matters can be burnt, when the plant-substance is still further resolved into volatile matters and a small proportion of ash.

Elements of Plant Food.—The chemical elements out of which the plant constructs its organic substance are carbon, hydrogen, oxygen, nitrogen, and sulphur. These exist in the organic substances, the carbohydrates and albuminoids, forming the cell-walls and cell-contents. They constitute the larger portion of the dry organic matter, and are driven off during combustion, as carbonic acid, water, and ammonia. The sulphur is not thus driven off, but remains behind, united with certain elements in the ash. The elements existing in the ash of plants are present only in very small quantities, but are essential to the life of the plant. These are phosphorus, iron, calcium, magnesium, and potassium. The carbon, forming half the dry weight of the plant, is obtained from the atmosphere; hydrogen, chiefly by the decomposition of water, and perhaps a small quantity from ammonia salts; oxygen from water, from the carbonic acid of the air, and also a small quantity from salts containing oxygen in the soil; nitrogen from the nitrates and ammonia salts in the soil—it is not taken up from the nitrogen[1] in the air, but it may be taken from organic matter, as in the case of the carnivorous plants, parasites, and saprophytes. The sulphur is obtained from salts occurring in the soil, such as calcic sulphate, part of the lime being removed by the formation of crystals of calcium oxalate in the cells of deciduous and other parts of plants. The elements used by the plant in forming its carbohydrates and albuminoids are thus obtained from the atmosphere, water, and the soil. The other elements are not directly needed for the formation of the cell-walls and protoplasm of the plant, but are found to be essential to the life of the plant, as the different chemical processes do not go on without their presence. Thus phosphorus[1] bears some relation to the albuminoids, as these are only formed when phosphates are present in the cells. Iron is also necessary, and is taken from the soil in the form of chloride or sulphate, but it is only needed in minute quantities. If entirely absent, the green colouring matter in the chlorophyll grains is not formed, the granules having only a yellowish etiolated appearance, even if exposed to light. If iron be added in minute traces to the food of such a plant, it rapidly develops chlorophyll in the granules. If potassium in the form of potash salts be not present, no assimilation and formation of starch goes on in the chlorophyll-bearing cells. In all parts of plants rich in starch or sugar, potash salts are met with in abundance, the potassium being in combination with some organic acid. Calcium and magnesium are also essential, but their special functions are unknown. They are taken up as phosphates, nitrates, sulphates, or chlorides, from the soil.

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[1] This statement needs modification in the case of Leguminosæ and Gramineæ.

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[1] Phosphorus is an important constituent of the nucleus.

Water Culture.—Bulbs, as those of the hyacinth, contain a large store of nourishment, and when placed in glasses and supplied with pure water, the leaves and flowers are developed at the expense of the reserve matters stored up in the bulb, in addition to the substance assimilated by the green leaves. The system of water-culture, from which so much regarding the history of the nutrition of plants has been learned, is somewhat like that of cultivating hyacinths in glasses. Seeds are, however, used instead of bulbs, and solutions containing known quantities of the mineral ingredients of plant-food are used instead of pure water. All the necessary substances can be given to the plant by water-culture, when proper precautions are taken to preserve the plant in a condition of health.

Many substances are occasionally or frequently met with in the ashes of plants, which have been proved by water-culture to be non-essential. Thus silica occurs in large quantities in most grasses, but they can be grown quite healthily without it. Chlorine has been found to be essential for the nutrition of the buckwheat. Iodine and bromine exist largely in sea-weeds, but seem non-essential elements, at least to the higher plants. Sodium is present everywhere, and always appears in the analysis of the ashes of plants, but does not seem to be an essential ingredient of plant food. Lithium, zinc, and copper also occur; the zinc and copper entering into the composition of plants growing near metallic mines, as in *Thlaspi alpestre*, var. *calaminare.* Aluminium is a constituent of the ash of certain species of Lycopodium. Manganese, cobalt, nickel, strontium, and barium have also been met with in exceptional cases. Thus the essential elements of plant-food are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, iron, magnesium, potassium, and calcium. The non-essential or accidental ingredients are silicon, iodine, bromine, sodium, lithium, zinc, copper, and aluminium.

Assimilation and Metastasis of Assimilated Materials.—Assimilation is a process of deoxidation, the carbonic acid of the atmosphere is split up in the chlorophyll-bearing cells of the plant under the influence of light; the carbon is fixed by being united with the elements of water in the plant, and the oxygen is liberated. By the process of assimilation, carbohydrates are formed, and the dry weight of the plant increased. The carbohydrate usually formed as a result of assimilation is starch [1]—occasionally fat, rarely cane sugar. Assimilation only goes on in the cells containing chlorophyll, and only when there is a sufficient amount of light, hence it does not occur in all cells or in all plants; neither is it a constant process, as it ceases during darkness. After the carbon has been thus fixed, and some assimilated carbohydrate formed, the assimilated matters undergo further changes. They change their positions, removing from the cells in which they were formed to others, or the assimilated matter at once goes to form new cells. Generally the change of position is accompanied by a change in chemical composition. This is the process of Metastasis. The two processes may thus be contrasted:—

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[1] It can be shown by Fehling's solution that dextrose precedes starch as a product of assimilation.

Assimilation.	Metastasis.
1. The elaboration of the inorganic elements contained in CO_2 and H_2O into organic compounds (carbohydrates).	1. The change of one organic compound into another.
2. Occurs only in cells containing chlorophyll.	2. Occurs in all cells of the plant, whether containing chlorophyll or not.
3. Takes place only under influence of light.	3. Is a constant process inpendent of light.
4. Much oxygen is liberated.	4. Oxygen is taken up, organic matter is oxidised, and equivalent quantities of carbonic acid liberated.
5. The dry weight of the plant is increased by the fixation of carbon and formation of carbohydrates.	5. The dry weight of the plant is diminished by the loss of weight from oxidation and liberation of carbonic acid.

Examples of metastasis can be seen in the potato and sugar-beet. In the potato, starch is formed in the chlorophyll-bearing cells of the leaf by assimilation. By metastasis this starch is changed into a glucoside in the stems, and is converted back into starch in the tubers, where it is stored up as a reserve material for the future use of the plant. The sugar-beet forms starch in its leaves, but in the leaf-stalk this is converted into grape sugar, and into cane sugar in the thick tap-root in which it is stored up.

The growth of plants is a result of assimilation. The size of leaves depends on the quantity of substance assimilated while they are unfolding. Starch can be seen forming in the leaves, but only when there is an excess produced, more than is required for the immediate wants of the plant. Generally, plants form an excess of assimilated substance, and this is stored up as 'reserve material' in special 'reservoirs of nutrient matter,' such as thickened roots, tubers, stem-tubers, rhizomes, bulbs, &c. The medullary rays in the stem of dicotyledonous forest trees are filled with starch, as reserve material, in winter. The leaves of many evergreens serve as reservoirs, the nutrient matter passing over into the stem just before the leaves fall off. Seeds also have large stores of reserve material of different kinds in the endosperm (the so-called albumen) and perisperm, or in the cotyledons. Owing to the presence of this reserve material, seeds can grow in the dark, the reserve matter being converted by metastasis into material necessary for the growth of the plant. Potatoes grow in cellars at the expense of the reserve matter. In dark cellars they form no green leaves, only scale-leaves with tubers (short thickened branches) in the axils. During the growth of seeds, bulbs, tubers, &c., in the dark, the actual dry weight is diminished, although the size has increased. Growth depends on the presence of *Constructive materials* in plants,—substances that can be used to form cell-walls and protoplasm. These constructive materials are starch, cellulose, sugar, fats, inulin, and the glucosides, such as tannin[1]; also albuminoids and asparagin. All these materials are stored up in the plant, and used in constructing its body.

Certain substances are formed during metastasis that are not constructive; they cannot be used again by the plant, and become as it were excretions. These are divided into two groups: (1) Degradation Products; and (2) Secondary Products of Metastasis. Degradation products are due to changes in the organised substance of the plant, but the substances formed can never be reconverted back into constructive matter. Thus wood, cork, and mucilage are products of degradation of the cell-walls, while degradation of protoplasm and chlorophyll also occurs. The products of degradation of the cell-wall are of importance in giving strength and solidity to the plant or affording protection. Secondary products of metastasis are formed in cells during metastasis, but remain inactive when formed, being apparently of no use to the plant. Many of these secondary products are, however, of great importance economically. As examples of secondary products we take some colouring matters, ethereal oils, resinous matters, many vegetable acids and alkaloids. Other substances are formed incapable of being again used by the plant, but serving important functions, as for example, the secretion of nectaries, to attract insects, essential in fertilisation; or the sweet material in the pericarps of many fruits, concerned in the scattering of the fruits and seeds.

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[1] Tannin is regarded by some observers as an excretion.

Reserve materials are chiefly fat, starch, inulin, &c. Fat or oil is common, especially in seeds, as in the colza, castor-oil, &c. Chocolate seeds, Brazil nut, and common nuts contain quantities of fat or oil. Starch is formed in the majority of cases. Inuline also occurs as reserve material, as in chicory, dahlia, Jerusalem artichoke and other Compositæ. Sugar is only rarely present as reserve material, as in the sugar-cane and sugar-beet. Cellulose itself also exists as a reserve material in some seeds. Albuminoids are also stored up in different forms. In most plants, transitory starch is formed, but it is at once used up in different ways.

Assimilated materials are either conveyed at once to the growing parts, or else if there is an excess, the excess is stored up in some reservoir, from whence after a period of rest it is again taken to be used in growth. In annual plants the assimilated materials are taken to the growing parts, and no reservoirs are formed, the only reserve matters being present in the seeds. In other plants a part of the material is stored up in a reservoir. The carbohydrates and fats are conveyed through the parenchymatous cells of the part, and these cells have an acid reaction. The albuminoids and possibly, exceedingly minute grains of starch are conveyed through the soft-bast,—the bast-parenchyma and sieve-tubes,—and these have an alkaline reaction.

Laticiferous tissues contain albuminoids, fats, starch-granules, and other carbohydrates, as well as numerous secondary products of metastasis, which remain inactive after their formation; but many are of importance to man, as opium, India-rubber, and many others.

Nutrition of Parasites.—Most parasites and all saprophytes contain little or no chlorophyll, and are in consequence generally of a brownish or white colour. In the higher ones the assimilating organs are defective, the foliage leaves being reduced to mere scales. These plants cannot assimilate. They exhibit metastasis, and take up oxygen, giving off carbonic acid. Some parasites are attached to roots, as Orobanche; others to stems by sucker-like roots, as the dodder; or the plant consists of a huge flower, as the Rafflesia Arnoldi of Java attached to the stem of a species of Cissus. Other parasites contain chlorophyll, and only take a portion of their nourishment from the host on which they grow, as the mistletoe. The Euphrasia and other plants belonging to the Scrophulariaceæ are green plants, parasitic on the roots of grasses. Saprophytes obtain their nourishment from decomposing organic matter, and as examples of colourless, or nearly colourless, saprophytes we may take Neottia Nidus-avis (the bird-nest orchid), Corallorhiza innata (the coral-root orchid), a rootless plant, with a coral like underground stem and root-hairs, and Epipogum aphyllum, a plant only once found in England.

Carnivorous Plants.—All plants must have nitrogen supplied to them. It is not taken direct[1] from the atmosphere by any plant, but is obtained from the nitrates and ammonia salts in the soil. Some plants do not obtain the whole of their nitrogenous food in this way, but obtain a part of it in a peculiar manner. These are the so called carnivorous plants. Generally they are plants growing in marshy places or in water, and most of them have defective roots, some being rootless. The sundews, Drosera, and butterworts, Pinguicula, grow in marshy places; Utricularia and Aldrovanda in water. The pitcher plants, Nepenthes, the water-pitchers, Sarracenia, and the Venus fly-trap, Dionæa, all grow in marshes. All these plants are furnished with special appliances for obtaining a supply of nitrogenous food, to supplement the small quantity to be obtained in other ways. The Venus fly-trap catches and retains insects by its peculiar trap-like leaves. The pitchers of Nepenthes and

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[1] See note, p. 89.

Sarracenia always contain a number of insects caught by the fluid in the interior. Utricularia has special bladders acting as traps to water-fleas and small water animals. The glandular hairs of the sundew catch and retain insects, the peculiar hairs or tentacles being irritable, and moving both when slight pressure is applied and when some nitrogenous matter comes into contact with them. The insects when caught and killed are in some cases, as in Drosera, Dionæa, and Nepenthes, covered with a secretion containing an acid, and a substance closely resembling pepsine, and a true process of digestion goes on similar to the digestion in the stomach of an animal. The digested matter is then absorbed, and during the absorption special movements are noticed in the protoplasm of the cells of the tentacle. These movements are described as movements of aggregation by Mr. C. Darwin. In Sarracenia and Utricularia, the animal matter is not digested, but becomes putrescent, and the putrescent matter is then absorbed; thus contrasting with those forms in which a true process of digestion precedes the absorption.

Respiration of Plants.—Plants, like animals, respire by taking up oxygen from the air, oxidising a part of their organic substance, and giving off carbonic acid, small quantities of water being probably formed at the same time. The process of assimilation was formerly mistaken for that of respiration. Plants cannot live without oxygen any more than animals, a proper supply of oxygen being necessary for the life of the protoplasm as well as for the oxidation of nutrient substances during the process of metastasis.

Throughout the whole life of the plant, by day as well as by night, oxygen is being taken up, and equivalent quantities of carbonic acid given off. During the day the carbonic acid thus given off may be at once decomposed and the carbon again assimilated; the large quantity of oxygen given off during the process of assimilation tending to obliterate all trace of the products of respiration. Germinating seeds and growing parts require large quantities of oxygen; so also do plants containing no green colouring matter. The taking up of oxygen and the giving off of carbonic acid are the cause of the loss of weight in germinating seeds, and also the cause of the evolution of heat. Whenever oxygen is taken up, heat is evolved. When flowers are expanding and the pollen ripening, rapid oxidation occurs, and consequently there is a considerable evolution of heat. In the Araceæ, the heat being confined by the spathe, the increase of temperature, which often amounts to from 4° to 10° Cent., may be easily detected. An increase of temperature amounting to about 0·6° Cent. is observed in the flowers of the Victoria regia. Funguses often show a considerable increase of temperature during the ripening of the spores. The increase of temperature during respiration is most marked in the malting of barley. The grain is soaked in water and then drained and thrown into heaps. The grains begin to germinate, and a marked rise in temperature is noticed. When the radicles are about half an inch long, the starch has been mostly changed into sugar; the malt is then dried rapidly to destroy the vitality of the seed. The sugar thus formed by metastasis produces alcohol when the malt is fermented. Fungi contain large quantities of phosphates, usually potassic, and are often phosphorescent and luminous during rapid oxidation. Movements of protoplasm and the movements of variation in sensitive plants cease entirely when the plants are deprived of oxygen and respiration is prevented.

Movement of Water in Plants.—Dependence on the presence of water is a characteristic of all living things. Whenever changes are going on in a part, or nutrient matter is required, water must be supplied. Not only is water contained in the cell-sap, but the cell-wall, nucleus, protoplasm, &c., are all saturated with water. There is both a slow and a rapid movement of water in plants. Some plants have both these movements, some only the slow; but none have the rapid movement only. The slow movement accompanies growth and nutrition, and depends on osmose or endosmose. The rapid movement occurs only during transpiration. When a dense fluid is separated by a membrane from a rarer fluid, the rare fluid will gradually pass through the membrane to the dense one, diluting it: this is the process of endosmose. A cell-wall forms a permeable septum or membrane; if there is a dense fluid on one side, and a rarer fluid on the other side, the latter passes through. A cell containing protoplasm, with a large proportion of water, will give up water to a cell containing a smaller proportion of water. Hence old parts of plants lose their water quickly, while the young parts retain it much longer, as is seen in the case of cut flowers. The young cells are filled almost entirely with dense protoplasm, while the old ones contain cell-sap with little or no protoplasm. The apex of a plant, the growing part, needs much water; its protoplasm being dense is able by osmotic action to take the fluid from the next cell, which is a little older and the protoplasm a little less dense; this one takes it from the one below, this from the next, and so on, until the old parts are reached and left dry if the plant is not able to obtain a renewed supply of water through the roots or cut portion of the stem. The slow movement takes place in the parenchyma and protomeristem tissues. The rapid movement serves a special purpose; it supplies the water that plants give off as watery vapour by transpiration through the stomata. The stomata communicate with intercellular spaces in the ground tissue where the fibro-vascular bundles chiefly ramify. The water is conveyed through the wood portion of the bundle, the xylem, reaches the intercellular spaces and the stomata, and there passes off as water-vapour. In the rapid movement the water passes, not by imbibition through the walls of the vessels, but through the cavities of the vessels and tracheides, helped by the osmotic influence of the xylem parenchyma.

Transpiration is the giving off of watery vapour through stomata, which are found chiefly on the under surface of leaves. In darkness the stomata are almost or quite closed, hence very little watery vapour is exhaled then, and if the temperature be low, the process becomes slow or tends to cease altogether. As light and heat are increased, so the quantity of watery vapour given off increases, and therefore the movement of water in the xylem of the fibro-vascular bundles increases in rapidity. Light is especially essential, for it acts on the stomata, which are closed in darkness and opened in bright light, even if the temperature be low. Thus a cabbage will transpire 17·0 grammes of water in an hour between 11 and 12 noon, with the temperature at 21° Cent., and the sun shining; only 1·5 grammes between 4 and 5 P.M., darkness beginning and the temperature 14° Cent. In the cherry laurel the following results were obtained—

	Water lost.
In sun, 1 hour	3·03 per cent.
In diffused light, 1 hour	0·59 ,,
In darkness (artificial) 1 hour	0·45 ,,

Another experiment was tried with the following result:—

		Water lost.
Sun, 1 hour	Saturated atmosphere.	25·96 per cent.
Diffused light, 1 hour		0·0 ,,
Sun, 1 hour	Dry atmosphere.	20·52 ,,
Diffused light, 1 hour		1·69 ,,

In both these experiments the shoots were placed in a bell-jar, one with very moist air, in the sun, one with moist air in ordinary diffused light. In the second case the air was thoroughly dried by passing through sulphuric acid and calcium chloride tubes. The shoot in the saturated atmosphere and in the sun lost more than a quarter of its weight, but lost nothing in ordinary diffused daylight. In the sun in dry air the loss was far less. A saturated atmosphere and sunshine can only occur very exceptionally, as for example in tropical climates and in green-houses; but it is essential for the proper treatment of plants in green-houses that attention should be paid to the effects of moisture and sunlight, for, unless carefully shaded from the sun, plants will give off so much water that they will droop and wither. The above experiments also show that plants do not take up water by their leaves from a moist atmosphere ; but that their roots must be supplied with plenty of water, which will be taken up by the root-hairs into the plant. The water thus taken up is not pure, but contains certain mineral substances in solution. These pass through the root to the fibro-vascular bundles of the stem, then to the leaf, where the water is transpired. When the leaves give off more moisture than the root takes up, the plants will wither or wilt. This fact is important in the culture of vines, as the roots are generally outside, and the stem and leaves inside the hot-house. If the leaves in the warm atmosphere give off a large quantity of water, while the temperature is very low outside, the plant will not be supplied with sufficient moisture, because the root can only take up water after a certain degree of temperature has been reached. For the same reason cut flowers wither. The leaves transpire more fluid than the stem can take up ; although for a certain time the stem is able to supply the necessary moisture, it cannot do so long. If the bark, the bast, and cambium are removed from a tree the water still ascends, for it is through the xylem or wood portion of the bundle that this rapid current passes up the stem. Experiments with coloured fluids also prove this. In order to ascertain the rapidity of the movement of fluid through wood, coloured fluids and solutions containing salts of lithium have been employed, as the least trace of this substance can be detected by the spectroscope. In the cherry laurel the rapidity of ascent is 40 inches per hour in sunshine; in other plants it is more rapid. Pfitzer obtained a rapidity of ascent of 22 metres per hour, or ⅓ metre per minute in Helianthus. It has been found that the wood-vessels have their cavities occupied by drops of water alternating with bubbles of air at less than atmospheric pressure. This and the capillarity of the vessels partly explain the ascent of water through the cavities of the vessels. By experimenting with plants in which accurate "double sawing" has been performed a very marked decrease in transpiration can be observed. The double sawing has interrupted the channels for the ascent of the water by cutting through the vessels and tracheïdes. The relative diminution in transpiration is more marked in the arboreous dicotyledons (in which vessels are characteristic of the xylem) than in conifers (in which tracheïdes occur instead of vessels). Cut flowers remain fresh much longer if the stem is cut under water, or if a second portion is removed from the stem, under water. The explanation is that the condition of the contents of the vessels is less disturbed by keeping the cut surface under water, not that a cut in the air causes by exposure an immediate change in the cut walls of the vessels.

It appears that the aërial parts of plants, as stems and leaves, cannot absorb water. We might expect that the upper surface of the leaf being exposed to rain could absorb some, but it does not; the upper side of the leaf is not usually provided with stomata, and is covered with a continuous cuticle often waxy and waterproof. The aërial roots of orchids do so, however, as in the epiphytic forms they have a special layer of cells, and must be almost entirely dependent on the water thus taken up. In forest trees having circumferential growth (dicotyledons), the channel for the conveyance of liquid in the fibro-vascular bundles gets larger and larger, because as the crown of leaves increases in size and more fluid is required, the channel is enlarged. In an ordinary forest tree, a full grown elm for example, the area of the leaves is very great, so that immense quantities of water are given off, and a very rapid movement required. In palms and ferns, after the maximum size of stem is attained, the number of leaves remains nearly constant. There is a crown of leaves, and as a new one forms an old one falls off, so the number and area of the leaves remain constant. Hence there is no provision for an increase in the size of the channel conveying the water, and no circumferential growth. Plants growing under water, or such parts of plants as are under water, are generally very soft, as the woody change does not take place in the xylem of the bundles. The bundles are thus often softer than the surrounding tissue, as no channels are required, the water being easily taken from the surrounding medium. The movement is apparently partly due to suction; the fluid evaporates, and fresh water enters to fill up the place by a process of osmose.

The root action in taking up water is also due to endosmose. It has been found that root-pressure occurs chiefly in the early spring, when the leaves are just opening. Then the pressure gradually diminishes until, when the plant transpires most, this root-pressure is entirely absent. The amount of pressure is determined by a manometer, consisting of a tube bent like the figure Ա, and filled with mercury. The pressure is shown by the height to which the column of mercury is raised. Thus the vine has been noticed to raise a column of mercury 804 mm., and the common stinging-nettle 354 mm. The root-pressure is the cause of the bleeding of trees in spring, seen in the birch, maple, and others. The fluid exuded consists of water, with mineral matters in solution, taken up directly from the soil, and the reserve matters from the stem. This bleeding ceases as soon as transpiration is established. Root-pressure is also the cause of the exudation of drops of water from small plants, as grasses, aroids, and Alchemilla. An exudation of fluid from cut branches, sometimes confounded with bleeding, takes place in winter when the part is warmed. The increase of temperature expands the air mixed with the fluid, and causes the fluid to be forced out of the stem. When cooled the air contracts, and fluid will be sucked in. This exudation or movement of liquid by increase of temperature can be well seen in winter and early spring before the leaves unfold and transpiration begins actively.

Movement of Gases in Plants.—Every cell requires oxygen, and every cell containing chlorophyll must be supplied with carbonic acid. Gases must therefore move about in plants, and even reach the interior of the cells. Thus gases move in the intercellular spaces of plants by changes in the equilibrium caused by the absorption or formation of carbonic acid; by changes in temperature and barometric pressure; and by the movements of the part due to the action of the wind. The rapidity of the movement will depend on the size of the cavity. Diffusion also occurs; the gas being absorbed by liquid, and thus entering into the interior of the cell. In the lowest plants diffusion is the sole cause of the movements, the cell obtaining gas directly from the surrounding water or air. Submersed water-plants without stomata take gases into their cells directly from the surrounding water by diffusion. Many of these plants contain large air-spaces, which facilitate the supply of gas to different parts of the plant. In these air-spaces the gas sometimes collects under pressure, so that when the part is injured the gas escapes with some force. In land plants, the stomata of the epidermis permit free entrance and escape of gas. These communicate with intercellular spaces throughout the plant. Other parts of land plants, especially those on which the cuticle of the epidermis is feebly or not at all developed, permit the direct diffusion of gas. The gases needed by the plant thus enter either by openings (stomata), or by diffusion through the walls. The latter mode is the only one in many unicellular or multicellular plants, as thallophytes and submersed water plants; while gases enter both by diffusion and by the stomata in the higher plants.

Molecular Structure of Plants.—Most of the phenomena of plant-life depend upon the molecular structure of plants. All plants consist of two things, water and solid substance, the quantity of water varying in different parts. Naegeli studied the solid substances carefully, and advanced the theory that the ultimate solid particles of plants are probably more or less crystalline, and that, as they are mostly, if not all, doubly refracting, they must have different degrees of elasticity in different directions. Each of these ultimate particles, or micellæ, Naegeli supposed to consist of a number of chemical molecules, and to be surrounded by a layer of water, the quantity of the water varying within certain small limits, the size of a micella also varying. The micellæ forming organised structures were considered held together by cohesion. By the micellar theory Naegeli sought to account for all the changes that take place in cells and cell-walls *e. g.* stratification of cell-walls, of starch-grains, growth taking place by the intussusception of new micellæ between pre-existing ones. The more or less complete rejection of Naegeli's micellar theory as an adequate explanation of organised structures is due mainly to the researches of Strasburger, who has shown that growth by apposition is general. For a detailed comparison of the views of Naegeli and of Strasburger, readers are referred to Vines's *Physiology of Plants* (Chap. III.). There are constant chemical changes going on during nutrition, and electrical changes also, but these are less known. So delicate is the balance of the equilibrium, that it is destroyed even by the influence of light, and plants decompose the carbonic acid of the air, fix the carbon, and give off oxygen.

CHAPTER V.

GENERAL CONDITIONS OF LIFE OF PLANTS.

Relations of Plant-life to Temperature.—It is only in exceptional cases, and under special conditions, that any marked development of heat occurs in plants; hence the temperature of the plant-body almost wholly depends on that of the surrounding medium, equality being produced by radiation and conduction. The underground or submersed parts of plants generally have the same temperature as the soil and water, as these media change their temperature very slowly. The thin parts of plants, such as stem and leaves, are generally colder than the surrounding air, owing to radiation. At night this is well-marked, especially when the sky is clear, the lowness of the temperature of the parts being shown by the formation of dew or hoar frost upon them. Transpiration and evaporation also cause the leaves to be cool during the day. The bark and wood of massive stems are bad conductors, hence their temperature rises and falls very slowly; from this it follows that during the day, while the temperature of the air is rising, these stems are generally colder than the surrounding air, and reach a maximum after the maximum day temperature has been passed; then they slowly cool, the atmosphere cooling much more rapidly, and hence during the night the stems are warmer than the surrounding air.

Every function of a plant can only be performed within a certain range of temperature, the function being equally in abeyance when the temperature is below a certain minimum and above a certain maximum. These limits may be taken as 0° Cent. for the minimum, and + 50° Cent. for the maximum, or between 32° and 122° Fahr. When the temperature sinks below 0° Cent. the functions of almost all plants cease, and if the temperature sinks still lower many plants are killed. So when the temperature rises above + 50° Cent. the functions cease to be performed, and a further rise rapidly kills most plants. Few plants are active at all temperatures throughout the whole range from 0° to + 50°. Generally the range is much more limited. Thus the germination of the seeds of Indian corn only takes place when the temperature has reached + 9·5° Cent., that being the minimum. The maximum is + 46·2° Cent., and above that temperature no germination of Indian corn takes place. The actual range between the minimum and maximum is thus 36·7° Cent.

As the temperature rises from the minimum, the activity of the function increases with the rise in temperature until a maximum of activity is attained, called the *optimum*. After the optimum is reached, the activity of the function rapidly decreases until the maximum temperature is reached, and all activity has ceased. Thus in the Indian corn the optimum of germination is + 33·7° Cent., the increase of even a few degrees of temperature causing a rapid decrease in the activity. The range from the minimum to the optimum is thus 24·2° Cent., while that from the optimum to the maximum is only 12·5° Cent. The difference between plants from warm and cold climates is shown by the minimum, optimum, and maximum temperatures. Thus in the germination of barley, wheat, Indian corn, and pumpkins, we have the following result :—

Name.	Minimum.	Optimum.	Maximum.	Range.
Hordeum vulgare .	+5°	+28·7°	+37·7°	32·7°
Triticum vulgare .	5°	28·7	42·5	37·5
Zea Mais . .	9·5	33·7	46·2	36·7
Cucumis Pepo .	13·7	33·7	46·2	32 5

The destructive influence of high temperatures on plants depends almost wholly on the quantity of water in the part. Thus parts with little water in the protoplasm, as seeds, withstand not only a high temperature, but also a very low one. Dry peas may be exposed to a temperature of +70° Cent. for one hour without losing their germinating power. If, however, they are previously soaked in water they are killed by a temperature of + 54° Cent. The ordinary watery part of plants cannot bear the prolonged action of a temperature higher than + 50° Cent. in air and + 45° Cent. in water without being killed. Some seeds will even withstand higher temperatures. Thus in Australia the seeds of Clianthus are put before sowing into a vessel and boiling water is poured upon them, the seeds remaining in the water until it is cold.

Plants are easily injured or killed by exposure to low temperatures. Parts containing little water may be subjected to intense cold without injury. Such plants as lichens, funguses, and mosses withstand extreme degrees of cold, and are also uninjured by being dried up. Seeds, and the buds of trees, are not injured so long as they contain little water; but as soon as the seeds begin to germinate or the buds to open, and large quantities of water are present in the cells, then the injurious action of frost at once becomes apparent. The injury is caused by the water separating from the protoplasm and other contained substances, and becoming frozen outside the cells, as the water does not freeze inside the cells. The ice crystals often form in quantities, causing considerable injury to the tissues; but the greatest injury is done by the forcible abstraction of water from the protoplasm. If thawing be gradual, the formation of ice does not injure some plants, and the tissues recover, the water being again absorbed. If, however, the thawing be very rapid, the water suddenly liberated is not absorbed, and destruction of the part follows. In many plants, frost at once causes the death of the part, whether thawing be slow or rapid. Frost-splitting of the stems of evergreen shrubs, such as the Portugal Laurel, is not uncommon when the temperature sinks very low. The splitting is due to the contraction of the bark and outer layer of wood by the cold; hence as soon as the temperature rises the contraction ceases, and the openings close up without injury to the plant. Cold often causes a change in the colour of many evergreen leaves. Some leaves, as those of Taxus, Juniperus, and Buxus, lose their colour, and become brownish, yellowish, or rusty; while others, as those of Sedum and Mahonia, become red on the upper surface. In the former the chlorophyll grains become disorganised, the whole protoplasm becoming cloudy and of a brownish or yellowish colour. In the latter the grains of chlorophyll remain unaltered in colour or appearance; but coloured masses, either red, or pale yellow, occupy the upper part of the cells. Here the red-colouring matter is soluble in water, and gives, on spectrum analysis, the same bands as the red-colouring matter of flowers. The change is due to the cooling of the part by radiation. Light does not cause any alteration, and the green colour is restored when the temperature rises. The restoration is a slow process, while the change in colour may be effected in a single frosty night.

Relations of Plant-life to Light.—No assimilation can go on without light; hence growth, when dependent on assimilated matter, is dependent on light. Plants containing no chlorophyll, and parts of plants that do not assimilate, are independent of the action of light. Funguses grow well in the dark, mould appearing on substances even in the deepest darkness, and others growing in mines or cellars, or like the truffle, living underground. The growth of seeds, tubers, and bulbs is independent of light, as is also the formation of wood in the cambium layer, and the development of new cells in buds, or at the apex of the root. As in the case of temperature, so with light, a certain minimum, optimum, and maximum are found to exist. The limits, however, are not well defined, as we possess no instrument equivalent to the thermometer enabling us to measure the intensity of light. In the absence of light, chlorophyll-bearing parts do not assimilate, and if the deprivation be continued for some time the chlorophyll granules become destroyed. When a portion of a green plant is taken into a dark box while the rest remains freely exposed to the action of the light, certain changes are exhibited by the parts grown in darkness. Thus all chlorophyll-bearing parts are blanched or etiolated, and are therefore of a pale colour, while the size of the parts becomes greatly modified. The leaves are exceedingly small and imperfectly developed, the growth of the leaf depending to a great extent on the supply of matter assimilated by the leaves themselves in their young states. The internodes, on the other hand, are greatly elongated, thus offering a marked contrast to the leaves. The light exercises a retarding influence on elongating parts; hence in the absence of light the growth is excessive. Parts not containing green colouring matter, as parts of the flower, are not generally altered by the absence of light, and retain their normal size and appearance. Such an experiment as the above shows that there is a two-fold action of light, one chemical, the other mechanical.

The chemical actions of light are shown, first, in the formation of chlorophyll, and second, in the assimilation in chlorophyll-bearing cells. Parts in the dark do not form chlorophyll. The granules are formed, and are apparently of the normal size and shape, but instead of chlorophyll, a yellow modification of it, called etiolin, is produced. When etiolated parts are exposed to light and heat, the chlorophyll is developed, and the parts assume their normal appearance. The seed-leaves of many pines and the leaves of ferns become green in darkness, thus affording remarkable exceptions to the general law. In the ferns, however, the chlorophyll grains formed in darkness are smaller than those normally produced. The dependence of the process of assimilation on the presence of a proper amount of light and a sufficiently high temperature has already been described. The effects of different quantities of light may be seen in the results of the following experiments. Twelve seeds of Indian cress were selected of as nearly the same size and weight as possible, and four of these seeds were placed in each of three pots. No. 1 was placed in darkness. The result was a gradual loss of weight during germination, and ultimate death from exhaustion, the plantlets only living as long as any assimilated substance remained in the cotyledons. The plants being in darkness were unable to assimilate new matter for themselves. No. 2 was placed for seven hours every forenoon in diffused light at a window facing the west. Germination readily took place, and the plants were permitted to grow for three months. At the end of this time they had gained five grammes of dry weight. No. 3 was placed constantly at a west window, so that they got direct sunlight in the afternoon. These in three months had gained twenty grammes of dry weight. The chemical action of light is limited almost entirely to the rays at the red end of the spectrum. Experiments by Engelmann and others show that the rays between B and C of the solar spectrum, *i.e.* at the junction of the red and the orange, not the yellow, are most active in assimilation.

The mechanical action of light depends on the violet end of the spectrum, the red rays producing no more effect on the plant than if it were in darkness. The plasmodia of some Myxomycetes move freely during darkness, and retreat when light appears. The protoplasm in the interior of cells is also influenced. Hence it is that some plants are paler in weak light than when the light is strong. This is due to the change in position of the protoplasm and chlorophyll, the granules being applied closely to the side wall in darkness, to the front and therefore most illuminated wall in the day time. Light also acts on zoospores, some moving towards the light, others away from it. The retarding influence of the light on growing parts is due to the action of the blue rays. These rays also act on sensitive plants, red rays causing them to assume their night position.

Electrical Conditions of Plants.—The constant chemical changes going on in the interior of the plant give rise to electrical conditions. These have not, however, as yet been fully investigated. A considerable number of plants are known which, when touched by solid bodies, or otherwise irritated in certain parts, exhibit movements like those which are familiar in the case of "sensitive plants," and it has been found that, while these movements are taking place, electrical currents are produced similar to those generated in a muscle during contraction. Thus Venus fly-trap (Dionæa muscipula) when folding its leaves gives rise to a well-marked electrical current in the leaf and expanded petiole. A similar condition is exhibited by the peculiar stigma of Mimulus. The stigma has two flat portions which are expanded in a state of repose, but close up when irritated; an electrical current occurs during contraction. The peculiar dehiscent berry of the elaterium,[1] or squirting cucumber, also exhibits an electrical current when contraction of the pericarp occurs, and the seeds are scattered with considerable violence.

The sap of trees is a good conductor of electricity; hence it is probable that, owing to the different electrical conditions of the earth and air, plants may to some extent act in equalizing the difference between their electrical conditions. According to Osborne Reynolds, the destructive influence of lightning is due to the sudden conversion of the moisture in the plant into steam, thus causing disruption of the tissues.

Weak constant currents exercise little or no effect on moving protoplasm, a stronger current causes retardation, and ultimately stoppage of the motion. Changes in the form of the mass of protoplasm in the interior of a cell are caused by sufficiently strong electrical currents. These are similar to the changes produced by a high temperature.

Weak induction currents act on sensitive and irritable plants, in the same manner as a mechanical stimulus. In Desmodium gyrans a strong induction current permanently destroys the movement of the leaflets, but does not kill the plant.

Influence of Gravitation on Plants.—All parts of all plants are constantly influenced by gravity, and accordingly there is a recognisable relation between the formation of most parts of plants and the action of gravity. The solid massive stems of trees support the mass of foliage and branches, and prevent the sinking of the whole from the superincumbent weight. Climbing and twining plants, seeds, fruits, and water plants, often have special adaptations for overcoming the weight of the part, and thus supporting the foliage and flowers, scattering the seeds, or enabling the plant to float. The direction of the axis, upwards or downwards, the position of the branches, the position of the leaves are all more or less influenced by gravitation. The effects of gravitation on growing parts are spoken of more fully on pages 134-6.

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[1] Ecballium elaterium.

CHAPTER VI.

THE GROWTH OF PLANTS.

By growth, is meant an increase of volume, and a permanent change in form of a plant or part, due to the addition of new nutrient matter. The increase in volume and change of form occur together; hence a mere increase in volume due, say, to the imbibition of water, is not growth, neither is a mere change of form. The permanent change in form is due to the deposit of new matter, of constructive materials, from the protoplasm. The presence of these constructive materials is an essential condition of growth. The matter may be formed at once by assimilation, or it may be obtained from some reservoir, or from the older full-grown parts of the plant. Growth often takes place at the expense of matter from the older parts of plants. Growth occurs only when certain favourable conditions are present. These conditions are either external or internal. The external conditions are presence of water and proper nutrient matter, the presence of a sufficient amount of light and heat, and also the influence of gravitation. The internal conditions are very important, but very difficult to investigate, and as yet no answer can be given to the question why a leaf or shoot assumes a certain definite form and no other. All that can be said is that the internal conditions are inherited.

Characteristics of Growing Parts.—Growing parts have certain well-marked peculiarities. These are (1) The capability of swelling up by imbibition of water; (2) Extensibility; (3) They possess great flexibility, but little elasticity; and (4) They are in a state of tension. First, a growing part is capable of swelling up by the absorption, or imbibition of water or watery solutions. The water increases the quantity already existing between the molecules of solid matter forming the texture of the part, and permits new matter to be deposited in some way. By the absorption of water, and the consequent increase in size of the part, considerable pressure is exerted in neighbouring parts, and changes of form in those parts are a necessary result. Within certain limits a loss of water may also take place, and changes of form may be observed, due to loss of imbibed water. The second character is the extensibility of growing parts. When rapidly growing internodes are "pulled out," or extended in the direction of their length, they are permanently lengthened, not possessing elasticity enough to enable them to return to their original condition. As the internodes grow older the elasticity increases, and the extensibility diminishes. This is shown in the following table taken from Sachs—

Name.	Original length of internode.	Amount of temporary elongation.	Amount of permanent elongation.
	mm.	p. c.	p. c.
1. Cimicifuga racemosa	296	6·8	3·5
2. Sambucus nigra	26	18·0	5·4
Next older internode	65	3·1	1·1
Still older internode	115	·8	0·
3. Aristolochia Sipho	102·5	4.4	1·0
Next older internode	242	2.2	·4
4. Aristolochia Sipho	33·5	10·4	1·5
Next older internode	252·5	1·8	·4

In rapidly growing shoots with the tissues very tense from imbibed water, the extensibility is greatest near the apex. The extensibility diminishes towards the basal and older part of the shoot.

The third characteristic of growing parts is great flexibility and little elasticity. An internode when bent and then released, is found not to be perfectly elastic; for the part, if originally quite straight, remains more or less curved. If afterwards bent in the opposite direction to the first, the bendings being repeated four times, it is found on straightening the internode that its length may have altered, but that the permanent residual flexion diminishes with each bending. When the internode is bent it is found that the concave side is permanently shortened, the convex side permanently lengthened.

The following results are taken from Sachs:—

Name.	Length of internode.	Radius of curvature when bent.	Radius of curvature when left to itself.	Thickness of middle part of internode.
Valeriana officinalis (stalk of young inflorescence) . .	mm.	cm.	cm.	mm.
Before bending . . .	200			6
1. Bent		4	13	
2. Bent in opposite direction		4	21	
3. Bent as in (1) . .		4	23	
4. Bent as in (2) . .		4	24*	
Straightened . . .	201·5			
Vitis vinifera (young internode)				
Before bending . . .	47·5			5·8
1. Bent		2	4	
2. Bent in opposite direction		2	6	
3. Bent as in (1) . .		2	6	
4. Bent as in (2) . .		2	9	
Straightened . . .	47·5			
Vitis vinifera (older internode)				
Before bending . . .	133·8			7
1. Bent		4	8	
2. Bent in opposite direction		4	17	
3. Bent as in (1). . .		4	11	
4. Bent as in (2). . .		4	25	
Straightened . . .	133·			

* The radius of the curvature increases as the curvature diminishes.

Name.	Length of internode.	Radius of curvature when bent.	Radius of curvature when left to itself.	Contraction of concave side.	Lengthening of convex side.
Ligularia macrophylla 7·5 mm. thick . . .					
Before bending . .	199				
Bent		6	17	3·5	4·
Bent again		5	13	3·5	4·5
Bent in opposite direction		6	30	·5	1·5

A blow on a rapidly growing internode also causes flexion, often giving a permanently curved form to the shoot. It is obvious from the above that permanent alterations in curvature can be easily caused by bending, and are caused whenever the limits of the elasticity of the internode are passed.

The fourth characteristic is the tension of growing parts. The tension is due to different causes, such as, first, the turgidity of the cell from the hydrostatic pressure of the contents on the wall; secondly, the imbibition of water by the cell-wall, and consequent pressure on the surrounding cells; and thirdly, the pressure caused by changes in the size and forms of the cells during growth. The turgidity of the cell increases or diminishes according to the quantity of water taken up by osmose, and given off to neighbouring cells during growth. The turgidity can only be seen in such cells as have no visible openings in the walls, the porous openings being relatively so large that the fluid can readily escape. The turgidity of a tissue, such as a piece of pith consisting of similar cells, is due to the same cause as the turgidity of the individual cell. The imbibition of water by the cell-wall is the cause of considerable pressure. The more water the cell-wall can imbibe, the greater the pressure will be; hence some walls chemically and physically altered will, by imbibing more water than others, exercise greater pressure. As it often happens that different layers of the cell-wall are of different constitution, the power of imbibition varies from layer to layer. Loss of water by certain layers may also cause tension. The ripening of many fruits and the dehiscence of anthers are due to this cause. In other cases, as in the dehiscent berry of the squirting cucumber, the imbibition is the cause of the scattering of the seeds. The movements of the so-called hygrometric plants, as Selaginella lepidophylla, the rose of Jericho, the mesembryanthemum, the hairs of Andropogon, &c., are all due to imbibition. Tension is also caused by the change in the form and size of cells during growth. This process is worthy of note. By turgidity and imbibition the intermolecular network is stretched, and new particles of matter are deposited by apposition from the protoplasm. By this process, however, the tension is neutralised, but only to be again increased by the taking up of new water. The limit of the elasticity of the cell-wall is being constantly reached by turgidity and imbibition, but only to be as constantly neutralised by the apposition of the new solid matter.

The tension of growing parts is either longitudinal or transverse, that is, either in the direction of the length of the internode, or in the direction of the diameter of the part. *Longitudinal tension* can be very clearly demonstrated by taking a rapidly growing internode, and cutting off a portion at each side so as to leave a longitudinal lamella consisting of the central pith with wood, cortex, and epidermis on the right side and on the left. The internode having been carefully measured, a sharp knife is then taken, and the pith, wood, and cortex, with the epidermis rapidly isolated. It will then be found, when the strips are placed side by side, that they are of different lengths, and that each isolated part is quite flaccid. The original internode was rigid from mutual tension, and it will be found that the pith is passively compressed, and prevented from extending, while the epidermis is passively extended, as the separated pith will be found longer than all the other parts, while the epidermis is the shortest. This can be expressed in the following way—

$$E < C < X < P > X > C > E$$

P, the pith, is the longest and in the centre. On each side is X, the xylem or wood, shorter than the pith. The wood is therefore exercising a positive or active tension on the pith, while the pith is exercising a negative or passive tension on the wood. So with the next layer, C, the cortex, it is positive towards the wood, but negative towards the epidermis, E. Thus each layer is exercising a positive or active tension towards the one inside it, but a negative or passive tension towards the one outside it. The following table, taken from Sachs, shows the amount of lengthening or shortening in the different tissues. The length of the internode is taken as 100, and the percentage increase or shortening shown for the different parts, pith, xylem, cortex and epidermis. The plant taken is the elder (Sambucus nigra).

Number of internode. No. 1 the youngest.	Change in length of the isolated tissues in per cent. of the entire internode.		
	Epidermis and Cortex.	Xylem.	Pith.
I.	—2·6	—2·6	+4·0
II.	—2·0	—2·8	+5·5
III.	—1·5	—0·0	+1.5

These changes are not only observable in the internodes, but in the petioles of different plants. An easy method of showing the tension of the different tissues is to take a sharp knife and cut thin strips of tissue from without inwards, the curving and shortening of the different parts being readily demonstrated when the parts are perfectly fresh. When a fresh internode is split longitudinally into two halves, the portions curve. By placing the portions on a flat surface the radius of the curvature can be determined, and the lengthening and shortening of the different parts easily measured. The results of two such experiments on the bisected internodes of Silphium perfoliatum are thus given by Sachs—

Length of entire internode.	Radius of curvature of segment	Contraction of concave side.	Lengthening of convex side.	Semi-diameter of the internode.
mm.	cm.	p. c.	p. c.	mm.
1. 69·5 . .	4	2·8	9·3	3
69·5 . .	4	2·4	9·3	3
2. 190 . .	3–4	2·8	9·5	3·5
190 . .	3–4	2·6	10·8	4·5

Positive and negative tension exist on the inside and outside of each individual layer, as well as in the whole stem; hence the curving of each of the separate zones of tissue. Roots do not exhibit any well-marked tension of the tissues, except in the older parts. When the aërial root of an aroid is split longitudinally, the older parts curve outwards, while at the growing part the opposite curvature is observable. The intensity of the tension in each internode diminishes with the increasing age. The compressibility in the pith rapidly diminishes, and the extensibility of the wood rapidly disappears, that of the cortex and epidermis remaining longer. Old internodes cease to exhibit any tension, and it is also worthy of remark that the apex of the stem or vegetative cone also exhibits no longitudinal tension.

The cause of longitudinal tension is undoubtedly the greater rapidity of growth of the pith in each internode. It is at first too long and too broad for the stem, thus stretching the outer tissues, and continuing to do so until these tissues are ultimately able to overcome it, by the development of wood and bast. Then the activity of the pith itself diminishes, and soon the cells cease to be turgid. The activity and turgidity of the vascular tissue continue after that of the pith, and hence tension is exerted on the cortex and epidermis.

During growth *transverse tension* is produced as a result of the longitudinal tension just described, the pressure of the pith on the outer tissues influencing both their length and breadth. The most marked transverse tension occurs, however, in older stems, and is not due to the action of the pith, but to the circumferential growth of the stem. The tissues formed by the cambium ring tend to expand greatly in a tangential direction, but are hindered by the cortex and epidermis. Hence the outer layers are stretched by the action of the inner, and consequently the layers of a section when separated are found to have different peripheral lengths; each layer being in a state of negative or passive tension on its outside, of positive or active tension on its inside. The condition of transverse tension of xylem, phloem, cortex, and epidermis, may thus be expressed—

E < C < Ph. < X.

A thin transverse section of the stem, when examined microscopically, shows the different states of tension by the size of the different cells, while a transverse section of wood shows clearly a diminution in diameter of the most recently added wood as the season advances. Monocotyledons exhibit similar transverse tension due to circumferential growth, as in the tree Liliaceæ already described. Here, however, the pressure is due to the development of new ground tissue and new fibro-vascular bundles by the meristem layer in the cortex of the stem.

The formation of a tylose (described on page 9) is one of many illustrations of the transverse tension in a growing stem. The turgid woody parenchymatous cells are longitudinally compressed by the rigid vessels and fibres. The parenchymatous cell extends itself laterally, and gradually forms a tylose in the cavity of the vessel, as described. As a result of the transverse tension of the wood we have the occurrence of the splitting of the bark, so characteristic of the stems of many trees. These fissures become deeper and wider each year in February and March. At this time the wood is full of imbibed water, and contains the greatest amount of water possible, while the bark is dry. By the tension of the wood thus produced the fissures form or enlarge. Later in the season the cortical layers begin to swell up, and thus the pressure between wood and bark is relieved. But now the cambium layer becomes active, new wood is formed, and the tension gradually increases, to be still further increased by the drying and contraction of the bark by cold at a later period, the maximum being attained in autumn and winter. In addition to this peculiar yearly periodicity in the transverse tension of the stem there exists a diurnal variation. The tension diminishes from early morning to midday, or even early in the afternoon, when the minimum is reached; then the tension increases, and the maximum occurs in the early morning hours. This diurnal change in tension is due to the varying amount of water in the tissues during the day and night. During rapid transpiration by the leaves the tension is least; when transpiration is going on feebly, and water is accumulating in the tissue, the tension is greatest.

Periodicity of Growth in length of Roots, Stems, Leaves, &c.—Many parts of plants only grow for a certain time, and having assumed a definite form and size, no further growth is possible. In a few rare cases, as in the nodes of grasses, growth may begin anew under certain special conditions. Usually, in stems and roots, we can distinguish three regions, characterised by special peculiarities of growth. First, there is the growing point or apex, or vegetative cone, consisting of a mass of protomeristem. Here new cells are rapidly formed by division, the relative length, however, of the zone of protomeristem remaining nearly constant. Second, the zone of elongation. Few new cells are produced by division, but the increase in size of the cells is very great, hence the rapid elongation of this portion of the axis. Third, the full-grown part, the zone in which neither enlargement of cells nor formation of new cells takes place, although the cells are still active, and performing many chemical or physical functions. Proceeding from the apex to the base of a part, we thus distinguish the three important regions, viz.—

1. Region of protomeristem.
2. Region of elongating cells.
3. Region of mature cells.

The above applies both to roots and stems. In roots the pileorhiza covers the apex; in the stem no such structure exists. In stems, nodes and internodes occur, and this introduces a complication in so far that the nodes soon cease to grow, while the internodes continue to elongate. In the growth of the leaf no *punctum vegetationis*[1] exists; hence the leaf is limited in its growth in length, and not unlimited[2] like the root and stem. At first the leaf wholly consists of protomeristem, and usually all of it is converted into permanent tissue.

Every cell, passing through the stages already fully described, is first in the condition of protomeristem, then undergoes elongation, and lastly becomes mature. In growing parts every cell, in succession, undergoes these changes. Every cell, therefore, after its formation, begins at first slowly to grow, then reaches its greatest rapidity of growth, and ultimately growth declines, until at last it ceases. In a growing part, therefore, there is a zone of maximum activity of the cells, with slower growing cells on each side of it; and in the case of the stem this zone of maximum activity is constantly moving upwards as the part becomes fully grown. Sachs calls the period of growth from the formation of the cell to its maturity the Grand Period or Grand Curve of growth, to distinguish it from the small diurnal changes occurring during the grand period. The duration of the growth varies in different parts; hence it is that some internodes are shorter than others. It is easily noticed that the lowest internodes on a shoot are very short, then the length increases higher up the stem, and lastly the internodes again diminish in length on the upper part of the shoot. The growth of the leaf obeys the same law. Different plants grow with different degrees of rapidity; but the following examples taken from Sachs will serve to illustrate the general principles of growth in length—

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[1] More than one plant might be mentioned in which growth of the leaf by an apical cell, for a time at least, takes place.

[2] Unlimited in Lygodium.

Fritillaria imperialis.		Elongation of one internode during each period of 24 hours.	Mean temperature.
Date.		mm.	Cent.
March	20	2·0	+ 10·6°
,,	21	5·3	10·5
,,	22	6·1	11·4
,,	23	6·8	12·2
,,	24	9·3	13·4
,,	25	13·4	13·9
,,	26	12·2	14·6
,,	27	8·5	15·0
,,	28	10·6	14·3
,,	29	10·3	12·4
,,	30	6·3	12 0
,,	31	4·7	11·2
April	1	5·8	10·7
,,	2	4·4	10·2
,,	3	3·8	9·4
,,	4	2·0	10·6
,,	5	1·2	10·7
,,	6	0·7	11·0
,,	7	0·0	11·0

Here a few irregularities occur due to variations in the quantity of water in the ground.

The same changes are shown more rapidly, according to Sachs, in an internode of Humulus Lupulus.

Date.	Elongation in 24 hrs.	Mean temperature.
	mm.	Cent.
April 22	19·0	+ 14·9°
,, 23	25·0	14·5
,, 24	26·0	14·3
,, 25	17·2	13·9
,, 26	4·8	14·1

When transverse lines are placed at equal distances apart upon a root or internode, it becomes easy to observe the rate of increase in length of each of the individual parts. By this method it is found that close to the growing point the growth is slow, most

Phaseolus multiflorus. First internode divided into 12 portions, each 3·5 mm. long, No. 1 being the apex.		Root of Vicia Faba, divided into 10 portions, each 1 mm. long, No. 1 being the apex.	
No. of Zone.	Growth in 40 hours.	No. of Zone.	Growth in 24 hours.
	mm.		mm.
1 (apex)	2·0	10 (base)	0·1
2	2·5	9	0·2
3	4·5	8	0·3
4 (maximum)	6·5	7	0·5
5	5·5	6	1·3
6	3·0	5	1·6
7	1·8	4	3·5
8	1 0	3 (maximum)	8·2
9	1·0	2	5·8
10	0·5	1 (apex)	1·5
11	0·5		
12 (base)	0·5		

rapid at a little distance from it, then after the maximum is passed, the increase in the length of the parts is slow. This is shown in the tables from Sachs, given on the preceding page.

A comparison of these figures shows that the zone of maximum growth in the stem is further from the apex than in the root.

The grand period of growth is not limited to roots, stems, and leaves, but is equally applicable to the cell itself, to hairs and to the thallus, whether unicellular or multicellular.

In addition to the grand period of growth just described, there is a daily periodicity of growth in length, due to the alternations of light and darkness, the increase and diminution of temperature, &c. The mean growth during the day is greater than that during the night. The mean growth is also quicker during the afternoon than during the forenoon. The amount of light in forenoon and afternoon is about the same, but the temperature is higher in the afternoon, thus

Name.	Total growth taken as 100.		Afternoon growth taken as 100.	
	Day. 12 hrs.	Night. 12 hrs.	Foren. 6 hrs.	Aftn. 6 hrs.
	p. c.	p. c.	p. c.	
Bryonia	59·0	41·0	86·	100
Wistaria	57·8	42·2	71·	100
Vitis	55·1	44·9	67·	100
Cucurbita	56·7	43·3	79·	100
Cucurbita	57·2	42·8	81·	100

the increase in temperature is sufficient to cause the increase in the mean growth.

From observations made on the growth of plants under constant external conditions, it is evident that the daily periodicity of growth is wholly due to external conditions.

Influence of External Conditions on Growth.—Growing parts must have abundance of water supplied and also require heat and light. Further, growing parts are much influenced by gravitation. The action of heat on growing parts is quite similar to that already described in treating generally of the influence of temperature, viz., that there is a minimum, optimum, and maximum. This can be easily observed in the development of the radicle of germinating seeds, as given by Koeppen and Sachs. The seeds of Lupinus albus, Pisum sativum, and Zea Mais were kept at a constant temperature for forty-eight hours, in eight separate experiments, with the following results—

Temperature.	Lupinus albus.	Pisum sativum.	Zea Mais.
Cent.	mm.	mm.	mm.
+ 14·1	9·1	5·0	0·0
18·0	11·6	8·3	1·1
23·5	31·0	30·0	10·8
26·6	54·1 (optim.)	53·9 (optim.)	29·6
28·5	50·1	40·4	26·5
30·2	43·8	38·5	64·6
33·5	14·2	23·0	69·5 (optim.)
36·5	12·6	8·7	20·7

Light exercises a retarding influence on growth. This can be readily seen in parts of plants grown in a dark cellar, or plants grown in rather dark rooms. Potato stems grown in a dark cellar are elongated and blanched. The leaves are very small and are yellow, not green. Plants not properly lighted, such as those standing near a window, exhibit most markedly the effects of their position. This effect of light is often masked by the increased rate of assimilation which light also produces. Thus in an internode in darkness, great elongation occurs, in consequence of the active growth of the pith not being retarded by the development of wood, bast, and the cuticular layer of the epidermis. The longitudinal tension here comes into play, and the parts become abnormal. If exposed to light, the cuticle of the epidermis rapidly forms, wood and bast are developed at the expense of the assimilated matter, and growth is slow. In the case of leaves developed in darkness, the effect of assimilation is noticeable. The leaf grows at the expense of the substance it assimilates; but in darkness it cannot assimilate, as it has formed no chlorophyll and could not use it if it had. Hence the leaf remains small, not from the retarding influence of light, but from the absence of assimilation. In a plant partially illuminated, as when standing in a window, the stem bends so as to place its long axis parallel to the incident rays. In most plants the stems curve towards these rays, and exhibit Positive Heliotropism (or Heliotropism). To curve towards the light the convex side of the organ (side away from the light) must elongate more than the concave side.[1] Most organs of plants are positively heliotropic. Leafstalks always bend towards the source of light. Most stems do the same. Plants containing no chlorophyll also exhibit positive heliotropism, as the sporangia of Mucor, and the sporocarps of Claviceps purpurea. Some organs are negatively heliotropic, or bend away from the light, the convex side of the stem or zone of greatest growth being towards the light, instead of the concave side. The tendrils of Ampelopsis and Vitis are negatively heliotropic. The older internodes of ivy are negatively, the younger internodes positively heliotropic. The aërial roots of orchids and aroids are all negatively heliotropic. There seem to be, therefore, two kinds of negatively heliotropic organs: first, those in which the action is seen in the zone of maximum growth; and secondly, those (as in the ivy) in which the action is only shown in the older parts. The curving of heliotropic parts is slight at first, then it attains a maximum and at length rapidly diminishes.

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[1] See *note* 4, page 165.

The most refrangible rays of the spectrum are those chiefly concerned in influencing direction of growth. This can be shown by growing plants under double glasses, one containing a solution of potassium bichromate, the other of ammoniacal oxide of copper. The former permits all the rays from the red to the middle of the green to pass, the latter only the blue and violet. Experiments made with the spectrum show that the yellow rays which of the visible spectrum least retard growth, have no heliotropic effects.

Gravitation also exercises a powerful influence on growth. The stem and root are thus influenced, the two parts being often called the ascending and descending axis, because the former grows erect in the direction of the plumb-line, the latter grows downwards into the soil. The lateral parts of the stem, branches and leaves, are also influenced by gravity, while the lateral rootlets do not seem to be. When a growing stem and growing root are placed horizontally the growing end of the stem bends, the under-surface becoming convex, the upper concave. This causes the free end of the stem to grow upwards. In the root the reverse takes place, the upper surface becomes convex, the lower concave, and thus the apex of the root is directed downwards. The influence of gravitation on growing parts is called Geotropism. The main root with the concave side of the bent portion downwards is positively geotropic, the stem with the concave side upwards is negatively geotropic. Many stems, as rhizomes, are like most main roots positively geotropic. Presence or absence of chlorophyll does not affect geotropic parts. Main roots showing positive geotropism may be either positively or negatively heliotropic. The aërial roots of aroids and orchids are negatively heliotropic, but are not much, if at all, influenced by geotropism. The action of geotropism may be overcome by certain external influences. Thus when seeds are allowed to germinate in a zinc sieve filled with sawdust, the main rootlets are at first positively geotropic, but soon passing through the net-work into the dry air below, they exhibit hydrotropism, and return to the moist sawdust. That gravitation is the cause of geotropism may be shown by the action of centrifugal force on growing embryo plants. When such plants are placed on wheels rotating with sufficient velocity, the rootlets follow the centrifugal force and grow downwards and outwards, while the stem grows in the opposite direction, upwards and inwards. Geotropism is the response of the organ, as a whole, to the directive force of gravitation, the organ tends to place itself with its long axis parallel to the direction of the force. The result, if curvature is necessary to do this, is that one side of the root grows more than the other. It will be seen that, as in heliotropism, the organ, as a whole, is affected by the force, resulting in the unequal growth of the two sides. The bending occurs only in the growing part, and at the part growing most rapidly in length. A peculiar form of geotropism is seen in the nodes of the stems of grasses. The stem, which in its vertical position has ceased to grow at the nodes, will, when placed horizontally, begin to grow again at the base of the internode, and will exhibit negative geotropism, thus tending to become erect. It is in this way that wheat recovers its erect position after having been laid by a storm.

Bilaterality of Growing Parts.—Growing parts generally exhibit an inequality in the amount of growth at different parts of their length or circumference. In some cases the unequal growth is not due to the influence of any external condition, but depends wholly on internal causes. Thus the leaves of plants grow more rapidly at first on the under than on the upper side; hence the leaves bend over, and help to form the bud at the apex of the stem. Subsequently the upper side grows more rapidly, and the leaf bends in an opposite direction, the bud unfolding. Parts growing more rapidly on the upper side are called epinastic;

on the under side, hyponastic. The part is therefore bilateral, and exhibits movements as a consequence of the unequal growth, these movements being distinguished as movements of nutation. The nutations are spontaneous or automatic when due entirely to internal causes, as in the opening of leaves and the movements of twining stems.

In other cases the nutations are due to the action of external causes on growth. Such nutations are called paratonic or kinetic, as the movements of tendrils and the periodic movements of foliage and floral leaves. Nutation invariably ceases as soon as the part is full grown. Simple nutations in one plane, the result of epinasty and hyponasty, are seen in the leaves in the bud and in floral leaves. Most floral leaves are at first hyponastic, then epinastic. In Dictamnus Fraxinella the filaments of the stamens with unopened anthers are bent downwards by epinasty; those that have discharged their pollen are bent upwards by hyponasty. The plumule of dicotyledons generally behaves in the same way, the apex being at first bent downwards by epinasty, then becoming erect. Revolving nutation is produced by the successive growth of all parts of the organ. The result of this is that the apex of the part revolves in a spiral manner. Twining plants exhibit revolving nutation. The direction of the growth, and therefore of the rotation, may be from right to left or from left to right. The revolving nutation goes on until the part finds some solid support, when immediately it begins to twine round the support, at first in a loose coil, but afterwards with a tight grasp. The revolving end of the stem has comparatively small leaves, and long internodes. The first internodes of embryo plants, and the lateral shoots of twining plants do not exhibit revolving nutation. Most twining plants twine to the left, that is, in the contrary direction to the movement of the hands of a watch. As examples we may take Aristolochia, Convolvulus, Phaseolus. Those that twine to the right, or follow the movements of the sun, are hop, bryony, and honeysuckle. Rarely the direction of the movement varies in the same plant, as in Loasa aurantiaca, or varies in different individuals of the same species as in Solanum Dulcamara, some twining towards the right, others towards the left. Torsion occurs during revolving nutation, the stem becoming twisted in the direction of the nutation. The number of twists does not, however, correspond with the number of revolutions of nutation. The activity of the nutations depends on the energy of the growth of the part, and varies in different plants. Darwin gives the following table of the time required for one revolution, under favourable circumstances, in different plants—

Scyphanthus elegans . .	1	hour,	17	minutes.
Akebia quinata . . .	1	,,	30	,,
Convolvulus sepium . .	1	,,	42	,,
Phaseolus vulgaris . .	1	,,	55	,,
Adhatoda	48	,,		

Tendrils also exhibit revolving nutation, but differing from that of twining stems. It is immaterial which part of a twining stem comes into contact with a solid support; but in a tendril only one side, the lower or posterior, is capable of becoming concave when brought into contact with a solid body. The movements of tendrils are produced by revolving nutation when they have grown about three-quarters of their full length. If the tendril comes into contact with a solid support during its revolving nutation, then a new movement of nutation is produced, due to the stimulus received from contact with that support. As a consequence of this stimulus, the free end of the tendril twines tightly round the support. But the influence of the stimulus caused by pressure on the solid support is carried down to that part of the tendril below the support. Here twisting also occurs, but in the direction opposite to that of the upper part, a neutral zone remaining in the middle. By this action the stem is drawn tightly up to the solid support. Tendrils that have failed to reach a support, either form a loose single spiral (without any neutral zone) or wither and fall off. Most tendrils are metamorphosed stems—vine, Ampelopsis, passion flower, and Cucurbita. In other cases they are modified leaves or parts of leaves, as in Lathyrus aphaca (entire lamina); Pisum (parts of compound leaf); Tropæolum and Clematis (petioles). Ampelopsis has peculiar negatively heliotropic tendrils, with discs at the end.[1]

Torsion, or the turning of an organ on its own axis of growth, occurs not unfrequently in other parts, besides twining stems and tendrils. It is well seen in the leaves of Alstroemeria. Torsion is of two kinds, one occurring in erect parts, the other in those placed horizontally or obliquely. In the former the cause of torsion is internal, depending chiefly on the unequal growth of the inner and outer tissues, while in the latter the weight of the parts, geotropism or heliotropism, or external conditions are the exciting causes.

Periodic movements of nutation are seen in many growing foliage and floral leaves. These depend on the unequal growth caused by changes in external conditions during day and night, the increase or diminution of light and heat, and invariably cease when the parts are full grown. Some are epinastic when exposed to light and heat, hyponastic[1] during the night. In others the reverse takes place; hence in some plants the parts are open during the day, in others they are open during the night. Thus the foliage leaves of Chenopodium, Stellaria, Linum and Brassica rise during the night by excessive growth on the under side, while in Impatiens, Polygonum and Convolvulus the leaves fall during the night by growth on the upper side. Floral leaves generally open during the day by epinasty, and close at night by hyponasty. The movements of these parts are due to the induction of epinastic and hyponastic tensions by the changing intensity of light and heat. The extent of the movement as well as the degree of sensibility vary in different plants. The flowers of Colchicum autumnale, Crocus, Tulipa, and Ornithogalum all exhibit great sensibility to an increase or diminution of light or heat.

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[1] Photo-epinasty and photo-hyponasty in the sense used by Vines

Spontaneous movements of variation.—These occur in the lateral leaflets of Hedysarum gyrans. The leaflets rotate in darkness as well as in light if only the temperature be high enough, completing one revolution in from two to five minutes, when the temperature is above +22° Cent. Spontaneous movements also occur in Mimosa, Trifolium, and Oxalis when kept in darkness. Under ordinary circumstances the spontaneous movements in these plants are obscured by movements due to the action of light. Rapid changes in turgescence of the cells are undoubtedly the causes of these spontaneous movements.

Many leaves exhibit movements of variation due to changes in light and temperature. Such movements are periodic, and occur not only in irritable leaves, as in Mimosa and Oxalis, but also in plants not irritable to mechanical stimuli, as Marsilea. When the light and heat diminish, the leaves fold and assume the nocturnal position—the sleeping of plants; while during the day the leaves expand and assume the diurnal position—the waking of plants. The position assumed by the leaves varies; thus in Trifolium the leaflets fold up in the nocturnal position, while in Oxalis they fold down. The degree of sensibility varies very much, in some plants mere shade causes movement. These movements are due to changes in the turgidity of the cells, consequent upon the movement of water in the plant, and the variations caused by differences of temperature.

Parts exhibiting movements of variation may, under certain conditions, lose the power of motion for a longer or shorter time without being killed. Such stiffening may be due to extremes of cold and heat, to drought, and to the influence of various chemical agents. When the temperature is below +15° Cent. the plants are in a state of cold stiffening. At a temperature above +40° Cent., heat stiffening sets in. In Mimosa, stiffening produced by drought has been observed. Toxic stiffening also occurs. Thus the leaves of Mimosa cease to move in the exhausted receiver of an air-pump, owing to the deprivation of oxygen; also when placed in a vessel containing hydrogen, nitrogen, carbonic acid, or the vapour of anæsthetics, as ether or chloroform. Stiffening, sometimes permanent, as in Hedysarum, can be produced by strong electrical currents. Stiffening may also be produced by keeping the plant in darkness for some time. The opposite result may be produced by keeping the plant exposed to light for a long period, when a phototonic condition may be observed;[1] the plant then retains its motile condition for some days, even in the dark, but gradually loses the phototonus if kept in darkness.

CHAPTER VIII.

THE REPRODUCTION OF PLANTS.

ALL plants possess the power of multiplying them selves. Two distinct modes of reproduction may be described, occurring either together or separately. Usually, however, plants possess both modes of multiplication. The two modes are distinguished as the non-sexual or vegetative reproduction, and the sexual. The former is generally called Agamogenesis, the latter Gamogenesis.

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[1] It has just been shown that artificial rhythm can be induced in a growing stem or root.

The process of Agamogenesis consists in the detachment of single cells, or buds, or branches, naturally or sometimes artificially, and the production of a new individual directly from the detached structure without the intervention of any other cells. The process of Gamogenesis is essentially different. Two cells must be produced, both incapable by themselves of development beyond a certain stage, but when united, when the nucleus of the one becomes united with the nucleus of the other, capable of forming an embryo-plant. The two cells or masses of protoplasm generally differ from each other in size and appearance. The large mass is the germ or female cell, the small often active mass, is the sperm or male cell. After the union of the protoplasm of the sperm with the germ-cell, or fertilisation, the fertilised germ-cell develops a new plant. In a few rare cases, and under exceptional conditions, the germ-cell develops without being fertilised,—the so-called parthenogenesis (Chara crinita).

Agamogenesis or Vegetative Reproduction.—In the lowest group of plants, the Schizophyta, or Protophyta, &c., the multiplication seems to be wholly by division, no process of gamogenesis having as yet been discovered. In other groups different forms of non-sexual multiplication occur. Thus in many thallophytes, division of cells, or the formation of moving swarm-spores or zoogonidia, occurs. Others produce tetragonidia, endogonidia, or stylogonidia. Spores of many thallophytes, of all bryophytes and pteridophytes are non-sexual reproductive organs. In other cases these are multicellular, forming buds or gemmæ, or special structures, such as the soredia detached from the thallus of the lichen. In flowering plants many buds, normal or adventitious, serve to multiply the plants, as well as stolons, layers, and cuttings produced either naturally or artificially.

Gamogenesis or Sexual Reproduction.—This consists in the union of the two elements, male and female, to form a new cell capable of further development. The nature and origin, as well as the size and appearance, of the two sexual cells differ very much in different plants. The simplest form of Gamogenesis consists in the union of two cells, similar[1] in all respects, to form a new cell. This is called conjugation, and the product of the union of the two cells, the zygospore. This mode of gamogenesis occurs in many different thallophytes (Spirogyra, Mucor, Ectocarpus). The conjugating cells are either moving zoospores, or the cells are non-motile. In some of the plants slight differences in the appearance of the two conjugating cells become observable. In other plants the female, or germ-cell, is generally very large and non-motile, while the sperm cell is small and often locomotive. Usually the germ-cell remains as a wall-less mass of protoplasm enclosed in a special envelope of variable structure, but so formed as to permit the access of the sperm-cell, as it is only in brown seaweeds that the germ-cells escape before fertilisation. In some cases the germ-cell is surrounded by a wall. The sperm-cells are, in the lower plants, moving masses of protoplasm without a wall, and are usually furnished with vibratile cilia; rarely (as in Florideæ) they are without cilia. The ciliated sperm-cell of most cryptogams—the antherozoid—presents a great contrast to the nucleated pollen-tube, the fertilising agent in Phanerogams.

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[1] Not quite in every case (*e.g.* Spirogyra).

In the Phanerogams or seed-bearing plants, the germ-cell is usually a naked mass of protoplasm placed near one end of a large cell, the embryo-sac. The embryo-sac is the central structure of the ovule. In Angiosperms the ovules are contained in a special case, called the ovary, furnished with a peculiarly developed part, the stigma. The ovary and stigma are generally portions of a modified leaf, the carpel, forming the whole or part of the central structure of the flower, called the Gynœcium. The male cells are in the pollen grains developed in the interior of the anther, the upper portions of a series of modified leaves of the flower, outside the gynœcium, and distinguished as the Androœcium. When the pollen grain is applied to the stigma (Pollination) of the carpel (angiosperms or metasperms), the inner part of the wall develops into a long tube, the pollen-tube, which traverses style, if present, cavity of ovary, and ovule until it reaches the embryo-sac. Then the generative nucleus passes through the mucilaginous tip of the pollen-tube into the embryo-sac to the ovum with the nucleus of which it fuses. In Gymnosperms (*e. g.* pines, Cycads) the carpels do not form an ovary, the ovules are naked, and the pollen-grains are directly applied, in pollination, to the ovules.

In most plants gamogenesis and agamogenesis co-exist, the latter supplementing the former as it were, or sometimes taking its place almost entirely, so that some plants rarely produce sexual reproductive organs. In other cases gamogenesis and agamogenesis alternate,—the so-called alternation of generations.

Influence of Relationship on Sexual Cells.—The sexual reproductive cells may be produced close to each other or at some distance from each other, on the same plant; or on separate plants. Such conditions are known as hermaphrodite, monœcious, and diœcious. When the sexual reproductive cells are produced close together in hermaphrodite plants, the close relationship of the sexual cells is detrimental to the propagation of the species, at least in most of the higher plants. In some cases fertile union does take place between closely related cells, but chiefly in the lowest plants. In hermaphrodite flowers, where the stamens and carpels are developed close together and are therefore nearly related, we sometimes find arrangements for facilitating the application of the pollen to the stigma of the same flower; but in a great many cases there are elaborate contrivances for preventing any such union. Some of the more important causes preventing self-fertilisation may be here enumerated. In flowers with stamens and carpels, owing to the acropetal development of the parts, the andrœcium is formed before the gynœcium, hence the former is slightly older than the latter. During development the parts may become equally developed, and reach maturity together, or one may become mature more rapidly than the other. Hermaphrodite flowers, with the stamens and carpels mature together, are called synacmic; those in which they are matured at different times, dichogamous. In a synacmic flower self-fertilisation may occur, unless there is some obstacle to prevent it, or, as in Corydalis cava, the pollen is always impotent when it falls directly on the stigma of its own flower. In dichogamous flowers, when the stigma is ready to receive pollen, the anthers of the same flowers are either immature, or the pollen has already been scattered. Hence there are two forms of dichogamy, flowers being Proterandrous when the anthers are first mature, Proterogynous when the carpels become earliest ripe. Proterandrous flowers are met with in many Compositæ, in Geranium and mallows, as well as in numerous other instances. In the mallow the united stamens when mature and ready to shed their pollen, form apparently the central structure of the flower, hardly any trace of the gynœcium being observable. After the pollen is scattered, the free part of each filament bends back, and the protruded stigmas become largely developed and ready to receive pollen. In such a case the pollen from a young flower is required to fertilise the stigma of an older one, while self-fertilisation is impossible. Proterogynous flowers have the gynœcium mature first. As examples we may take among many others, the common Plantago and Aristolochia Clematitis. If a spike of flowers of Plantago lanceolata be examined at an early stage, the stigmas are seen protruding from the unopened flowers at the base of the spike. The stigmas protrude in succession from base to apex, and it is not until after the stigma has withered, that the perianth opens and the stamens are developed. In Plantago the pollen of old flowers must be applied to the stigmas of younger ones. The same is seen in the Aristolochia, the stamens being mature after the gynœcium.

There are often mechanical obstacles preventing self-fertilisation. These are often met with in synacmic flowers, as in the orchids, violets, Iris, and others. In orchids the pollen masses are so placed that unless removed by some external agent they cannot be applied to the stigma at all. In violets the anthers form a united ring round the style and open outwards, the stigma projecting above the syngenesious anthers. In Iris the three stamens are superposed to the outer parts of the perianth, the three inner stamens being entirely wanting; hence the three carpels are superposed to the stamens, the anthers being hidden and covered over by the petaloid styles. The stigma is so placed that self-fertilisation is impossible. In all these cases self-fertilisation is prevented by various mechanical obstacles. Another contrivance for preventing self-fertilisation is known as Heterostyly, the styles and stamens being of different lengths in flowers of different plants. Two varieties of heterostyly are distinguished. In the one the stamens and styles are of two different lengths, long and short—the dimorphic condition seen in Primula, Linum, and others. In one flower the style is long, Macrostylous, and the stamens are short. In the other flower the style is short, Microstylous, while the stamens are long. Fertilisation succeeds best when the pollen from the long stamen is applied to the long style, from the short stamen to the short style. The trimorphic condition occurs in Lythrum Salicaria, there being styles and stamens of three different lengths. The macrostylous flowers have intermediate and short stamens; the mesostylous long and short stamens; the microstylous, long and intermediate stamens. In this case the best results are produced when the pollen from a stamen of given length is applied to the stigma of the same length, as the pollen from the long stamen to the macrostylous flower.

In some plants peculiar imperfect self-fertilising flowers are produced in addition to the normally developed ones. The imperfect self-fertilising flowers are called kleistogamous, and are met with in Oxalis Acetosella, Impatiens Noli-me-tangere, many species of Viola, &c.

Self-fertilisation being the exception, and there being so many ways of preventing it in hermaphrodite flowers, the question arises how is the pollen applied? Fertilisation cannot take place unless the pollen be applied to the stigma, pollination being the necessary antecedent of fertilisation. The chief agents in pollination are the following:—(1) The *wind.* Flowers are called Anemophilous when pollination is effected by the wind. Many diœcious and monœcious plants are anemophilous. Thus the hazel and pine, among others, belong to this group. The pollen is always produced in quantity; usually it is rounded, and never spiny or sticky. The flowers are sometimes produced before the leaves (hazel), or situated at the ends of the shoots (pine), to facilitate fertilisation. The pollen of the pine causes the so-called sulphur showers in the neighbourhood of pine forests. (2) *Birds.* Flowers which are pollinated through the agency of birds are called Ornithophilous. The humming-birds of America, in seeking the nectar of flowers, act as agents for scattering the pollen. No ornithophilous flowers seem to be natives of Europe. (3) *Snails* occasionally carry the pollen, having been observed by Delpino to scatter the pollen in a species of Arum. (4) *Insects* are the most common agents in pollination: flowers thus pollinated are said to be Entomophilous. The insects belong to different orders. Many Lepidoptera, both butterflies and moths, are employed, being attracted by the colour, odour, and nectar of the flowers. Bright-coloured flowers (as Dianthus) are generally pollinated by the diurnal Lepidoptera or butterflies. Pale-coloured scented flowers (honeysuckle), by the nocturnal Lepidoptera or moths. The flowers of orchids are usually pollinated by moths, sometimes by wasps. Hymenoptera, as bees and wasps also help in this process. Bees are probably the most important agents in scattering pollen. The pollen grains of entomophilous plants are often spiny or covered with projections, by which they readily adhere to the hairy surface of the bee when it visits the flower to abstract the nectar. The Diptera, or two-winged flies, are also employed. The carrion flowers, and others having the odour or appearance of putrid flesh, are visited by flesh-flies. Many other Diptera pollinate flowers. A good example is afforded by Aristolochia Clematitis. The flowers are proterogynous, the andrœcium and gynœcium are united, and in addition there are mechanical obstacles sufficient to prevent self-fertilisation. The perianth is tubular, and before fertilisation is erect. In the narrow part of the tube hairs are placed pointing downwards, and permitting small Diptera to enter freely but preventing their return. If the insects have brought any pollen it is applied to the ripe stigma. The stigma now folds up, the anthers open, and the insect receives a new supply of pollen. The hairs in the tube next wither, and the insect escapes to visit and fertilise another flower. After fertilisation the perianth bends down and the upper part folds, so as to close the opening and prevent insects visiting flowers already fertilised.

Innumerable modifications in the method of fertilisation occur, the above being only a very brief outline.

Hybrids.—From the modes by which pollination is effected in plants, it is evident that not unfrequently foreign pollen will be applied to the stigma of a flower as well as pollen of plants of the same species. Pollen of different species may also be artificially applied; when perfect seeds are obtained by the application of pollen from one species to the stigma of another species of the same genus, the plants raised from these seeds are hybrids, with characters more or less intermediate between those of the two parents. Rarely hybrids are obtained between plants of different but closely related genera. These are called Bigeners. Between two species of the same genus, hybrids proper are produced; while between two varieties of the same species, we have the production of crosses. Plants not related systematically do not hybridise. In some natural families hybrids are easily produced even naturally, in others only with extreme difficulty. When plants hybridise they are said to possess sexual affinity. Every degree of sexual affinity exists, from complete indifference or absence of sexual affinity, to the most marked and easy production of hybrids. Some species of a genus possess marked sexual affinity, others of the same genus possess none. The same is even true of different varieties of one species. In writing the name of a hybrid it is usual to place the name of the pollen-yielding parent first. Thus Digitalis purpureo-lutea signifies a hybrid form, the ovules of D. lutea having been fertilised by the pollen of D. purpurea. It is generally possible to produce the reciprocal hybrid; that is, we may either have D. purpureo-lutea or D. luteo-purpurea. The characters of the two forms are not necessarily identical, one being often more variable, or having some special peculiarity, while in a few cases it has been found impossible to produce the reciprocal hybrid. Mixed pollen may be applied, when that having the greatest sexual affinity will fertilise the ovule, the pollen of the same species having of course the preference. When pollen of a different species is first applied, and then pollen of the same species, a hybrid will not be formed if the interval between the applications be short, but hybridisation cannot be prevented under such circumstances in Nicotiana in two hours, in Malva and Hibiscus in three hours, and in Dianthus in five or six hours. Combined hybrids may be produced when hybrids are fertilised by the pollen of another hybrid or another species. When the hybrid form is fertilised by the pollen of one or other of the parents, the offspring returns to the parent form in a few generations. Hybrids occur naturally, but the artificial ones formed by the art of the gardener, are of the greatest interest, as many of our most useful and beautiful plants have been thus produced.

CHAPTER IX.

THE CLASSES OF THE VEGETABLE KINGDOM.

THE study of the general morphology and physiology of plants is a necessary introduction to the study of the mode in which plants are classified. The object of the botanist is to obtain a morphological classification, one in accordance with natural affinities, one that will express the blood relationships existing between the different plants classified. Classification is thus a branch of morphology, and cannot be studied apart from it. The structure and construction of the various parts of plants, and the physiological changes parts undergo during development, must be studied before a morphological classification can be attempted. By a careful comparison of the structure of the nutritive and reproductive organs of plants, by the examination of the alternation of generations, such a special knowledge of the morphology of the plant is obtained, that by comparison with others, its relative position in the scheme of classification can be ascertained. Owing to the numerous gaps in our knowledge of the special morphology of plants, constant changes are liable to be made in the arrangements of the larger and smaller divisions; hence every classification, or modification of it, is not to be considered as final, but merely as representing the state of knowledge at the time of its publication.

Taking the Vegetable Kingdom as a whole, it can be subdivided into more and more special groups. The larger groups include all plants having certain great characters in common, while the smaller groups include those that are separated from the larger groups by having some special peculiarity in addition to the general character of the large group. We may take the following groups intermediate between the "kingdom" including all plants, and the "species" or unit, which is the ideal aggregate of individual plants possessing some common constant character, by which they can be separated from somewhat similar forms. The characters of species, however, are not all constant, hence certain modifications are distinguished as varieties. The following tabular view of the different divisions may be taken as representing the subordination of groups from the highest to the lowest:—Kingdom, Sub-Kingdom, Class, Order, Family, Genus, Species, Variety.

It is often necessary to subdivide still further, hence we have Sub-classes, Sub-orders, Sub-families, Sub-genera, Sub-species, and Sub-varieties, as well as others adopted merely for convenience.

The Vegetable Kingdom may be divided into the following Sub-kingdoms—

I. **Thallophyta.**—Plants of very simple construction, often unicellular, never possessing true roots or fibro-vascular bundles,[1] and usually without any separation into stem and leaf. The reproduction is very varied, and frequently there is no alternation of generations.

II. **Bryophyta.**—Plants usually have stem and leaf, rarely consisting of a thallus, never having true roots or fibro-vascular bundles,[2] developed either directly or more usually indirectly, from the spore, and bearing the sexual reproductive organs. From the fertilised ovum is developed a special structure (sporophyte generation), the sporogonium, containing the spores.

III. **Pteridophyta.**—The spore develops a small prothallium, a thallus-like structure, bearing the sexual reproductive organs (first generation). From the fertilised ovum is developed the second generation, a spore-bearing plant, with stem, leaves, and true roots, having these parts traversed by fibro-vascular bundles (sporophyte generation).

IV. **Phanerogamia.**—The plants possess roots, stems and leaves, traversed by fibro-vascular bundles, and develop ovules in a special part of the flower. These ovules, when they have arrived at maturity, after the fertilisation of the ovum in the embryo-sac, become the seeds, containing a more or less developed embryo, which by germination grows and forms a new plant.

Thus in Thallophytes alternation of generations is

[1] Macrocystis possesses sieve-tubes comparable to those in Cucurbita.

[2] Conducting strands are present in some mosses.

rarely marked clearly (Coleochæte), the sporophyte generation being usually undeveloped. In Bryophytes the gametophyte shows, as a rule, differentiation into stem and leaf, becoming less differentiated in the ferns and higher plants as the sporophyte becomes more pronounced.

These Sub-kingdoms can be still further subdivided into classes, having the following characters—

I. Thallophyta.

The four classes Schizophyta, Zygosporeæ, Oosporeæ, and Carposporeæ, instituted by Sachs, were based mainly on the mode of reproduction of the forms included. The investigations of the last few years have shown that the mode of reproduction should take a subordinate place in the construction of a natural system. Algæ and Fungi no longer are regarded as forming two parallel series of closely allied forms. The Fungi include isogamous (zygosporous) and oogamous (oosporous) forms, and are now considered an independent group with Algal ancestors of the group Siphoneæ, the connecting link on the fungal side being the Phycomycetes.

Class 1. *Myxomycetes* (Slime—Fungi).—Thallus, very unlike that in other Thallophytes, a naked nucleated amœboid mass of protoplasm (plasmodium). By some authors placed in the animal kingdom.

Class 2. *Diatomaceæ.*—Position doubtful. Unicellular, chlorophyll-containing. Motile, cause not understood. Membranes box-like, silicified. Multiply by simple bipartition and by auxospores formed in some cases by conjugation.

Class 3. *Schizophyta.*—(*a*) Forms containing chlorophyll: Cyanophyceæ. Thallus very varied. Cells nucleated, in some at least. Swarm-cells in Merismopedia. Sexual reproduction unknown. (*b*) Forms not containing chlorophyll: Schizomycetes or Bacteria. Closely allied to the Cyanophyceæ. Some forms exceedingly minute. Nucleus recently described in a Bacillus. Organised ferments. Multiply by fission and by spores.

Class 4. *Algæ.*—(*a*) Chlorophyceæ—green. (*b*) Phæophyceæ—brown seaweeds. (*c*) Rhodophyceæ or Florideæ—red, mostly marine.

Class 5. *Fungi.*—Thallus in some non-cellular, multinucleate, often a mycelium. Obtain their organic food as saprophytes or as parasites. Reproduction in many ways, isogamous and oogamous in same group (Phycomycetes). Sexual reproduction lost in some, apparently, by mode of life. Lichens are really Fungi, mainly of the Ascomycete group, with Algæ and Cyanophyceæ as hosts (*i. e.* the *fungus* and *alga* form a symbiotic organism).

II. Bryophyta (Muscineæ).

Class 6. *Hepaticæ.*—Usually the spore developes directly a plant consisting of a thallus, thallus-like stem, with imperfect scale-like leaves, or a bilateral thin stem, with two rows of leaves without midribs, and consisting of a single cell-surface. Rarely a third row of small scale-like leaves is developed on the under side of the stem. The thallus, thallus-like stem or normal axis, develops the reproductive organs, antheridia and archegonia. The ovum of the latter after fertilisation forms the sporogonium containing the spores, usually with elaters in addition, and rarely containing a columella. The sporogonium opens in different ways, regularly or irregularly, and when ripe breaks through the wall of the archegonium, which often forms a sheath-like structure surrounding the stalk bearing the spore case.

Class 7. *Musci.*—The spore develops a filamentous branching protonema, developing one or many buds; from these buds the leafy axis of the moss arises, a filamentous, rarely bilateral, stem bearing leaves, usually with a midrib. The reproductive organs, antheridia and archegonia, are developed at the apex, or on side branches, of the stem. The fertilised ovum of the archegonium forms the sporogonium, containing the spores, with a central columella. The wall of the archegonium is carried up on the sporogonium, and forms the calyptra. The sporogonium usually opens by a lid, and often has a complex structure.

III. Pteridophyta (Vascular Cryptogams).

Class 8. *Filicinæ.*—Plants with stem, leaves and roots. Stem usually unbranched; with a few leaves large and usually branched. The sporangia are developed on the underside, on the margins, or in the interior of ordinary or specially modified leaves or parts of leaves, not limited to special regions of the stem. The spores are either of one kind only, or there are two kinds, megaspores and microspores, in mega- and microsporanges.

Class 9. *Equisetinæ.*—Plants with a much branched stem, usually in whorls; with numerous small sheath-like toothed leaves; the roots monopodially branched. The sporangia developed in a cluster on the under side of stalked shield-like leaves, arranged in alternating whorls, and forming a compact spike or cone-like structure at the end of ordinary (green) or special (brown) stems. The spores are of one kind and furnished with hygroscopic elaters which, by keeping spores together, help, on germination of spores, in fertilisation.

Class 10. *Lycopodinæ.* — Root dichotomously branched. Stem usually with a number of small leaves, branching usually monopodial, but simulating dichotomy. The sporangia are developed singly at the base or in the axil of ordinary or special leaves, usually limited to the upper part of the axis. The spores are either of one kind or two kinds, micro- and megaspores, and developed in micro- and megasporanges.

IV. Phanerogamia (Spermaphytes).

A. GYMNOSPERMS.

Class 11. *Gymnospermia.*—Ovules not enclosed in a special case, the ovary. The pollen grains or microspores are applied directly to the apex of the nucellus of the ovule on pollination. The embryo-sac is filled with endosperm (prothallus) before fertilisation. Several archegonia are formed from individual cells of endosperm (female gametophyte). Fertilisation of the ova of these results frequently in Polyembryony.

B. ANGIOSPERMS.

Ovules enclosed in a special case, the ovary. The pollen grains or microspores are applied to the stigma on pollination, each sending a pollen-tube down to the ovules contained in the ovary. The endosperm forms in the embryo-sac after fertilisation. The ovum at the upper end of the embryo-sac develops after fertilisation directly into the embryo and suspensor.

Class 12. *Monocotyledones.*—Embryo with one cotyledon. Seed, usually with copious endosperm, rarely wanting[1] or replaced by perisperm. Radicle usually ceasing to grow after germination, and replaced by adventitious roots. Stem with separate closed fibro-vascular bundles scattered in the ground-tissue. Leaves rarely branched with reticulated veins, usually simple with parallel veins. Flowers typically pentacyclic trimerous; generally with the outer and inner whorls of the perianth similar and petaloid.

Class 13. *Dicotyledones.*—Embryo with two cotyledons, rarely with one or none. Seed often without endosperm. Radicle usually developing greatly after germination; the cotyledons either remaining below or coming above ground and then usually assimilative. Stem usually with separate open fibro-vascular bundles arranged in a ring in the ground tissue; in most cases with a cambium ring developing new wood on the inside and new bast on the outside, and thus giving rise to circumferential growth. Leaves rarely sessile, often branched with reticulated venation. Flowers typically tetracyclic pentamerous; the perianth in two whorls, the outer forming the green calyx, the inner the corolla; often, however, the perianth is wanting, or consists of a single whorl.

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[1] It is important to remember that seeds of monocotyledons are not necessarily albuminous, and those of dicotyledons exalbuminous.

NOTES.

Note 1 (p. 13).—The nucleus consists for the most part of U-shaped threads of a special phosphorised albuminoid substance called nuclein, the interspaces being occupied, and the whole surrounded by albuminoid matter not differing much from protoplasm.

The nucleus divides either directly, by fragmentation, as in the long internodal cells of Chara; or indirectly, by caryokinesis, when special rearrangement and division of the nuclein takes place, producing the caryolitic figures so well seen in the staminal hairs of Tradescantia. In many instances—Vaucheria, Caulerpa, Mucor, &c.—large numbers of nuclei occur in cells, and such plants have been called by Sachs, non-cellular. In Cladophora the cells are multinuclear, with occasional walls, and the structure is thus intermediate between cellular and non-cellular; while in Chara the nodal cells are distinct, but the internodal tubes are non-cellular.

Note 2 (p. 65).—Sachs has recently shown that the various organs of plants may occur in four distinct stages of differentiation, viz. rudimentary, typical, modified, and reduced; and he further considers that all organs of plants belong to root and shoot, if vegetative, and to antheridium, archegonium, and sporangium, if reproductive.

Note 3 (p. 79).—To avoid confusion Bower has proposed to call the stem and leaf of a non-vascular cryptogam the caulidium and phyllidium, indicating that they are members of the gametophyte or oophyte generation, and are therefore not homologous to the caulome and phyllome of the sporophyte generation of the higher plants.

Note 4 (p. 134).—Heliotropism includes the action of solar radiations whether light or heat, and it is best to distinguish between phototropism, or the action of light in causing curvature of growing parts, and thermotropism, or the corresponding action of heat.

Note 5.—Monostely and Polystely. Van Tieghem proposes to call the vascular cylinder as found in the stems and roots of most Phanerogams a *stele*. Phanerogams, with few exceptions, and all *embryonic* vascular Cryptogams are *monostelous*. Most adult Vascular Cryptogams are polystelous, owing to the repeated bifurcation of the original single stele; each 'concentric vascular bundle,' as at present understood, is homologous to the single stele (vascular cylinder) in Phanerogams. (See Scott, *Annals of Botany*, 1891.)

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